The
ENGINEERS' DIGEST

REVIEW OF ENGINEERING PROGRESS ABROAD

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THE ENGINEERS' DIGEST

REVIEW OF ENGINEERING PROGRESS ABROAD

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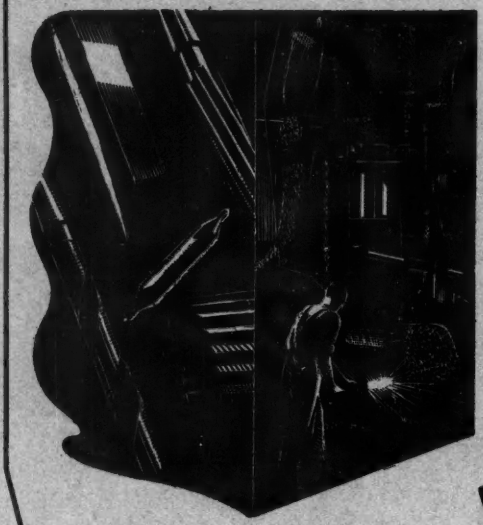

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Q. What are the advantages of BRYANISING

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(2) It provides the tightest possible bond between the ferrous bond and the coating of zinc.
(3) It provides absolute uniformity in the thickness of the coating.
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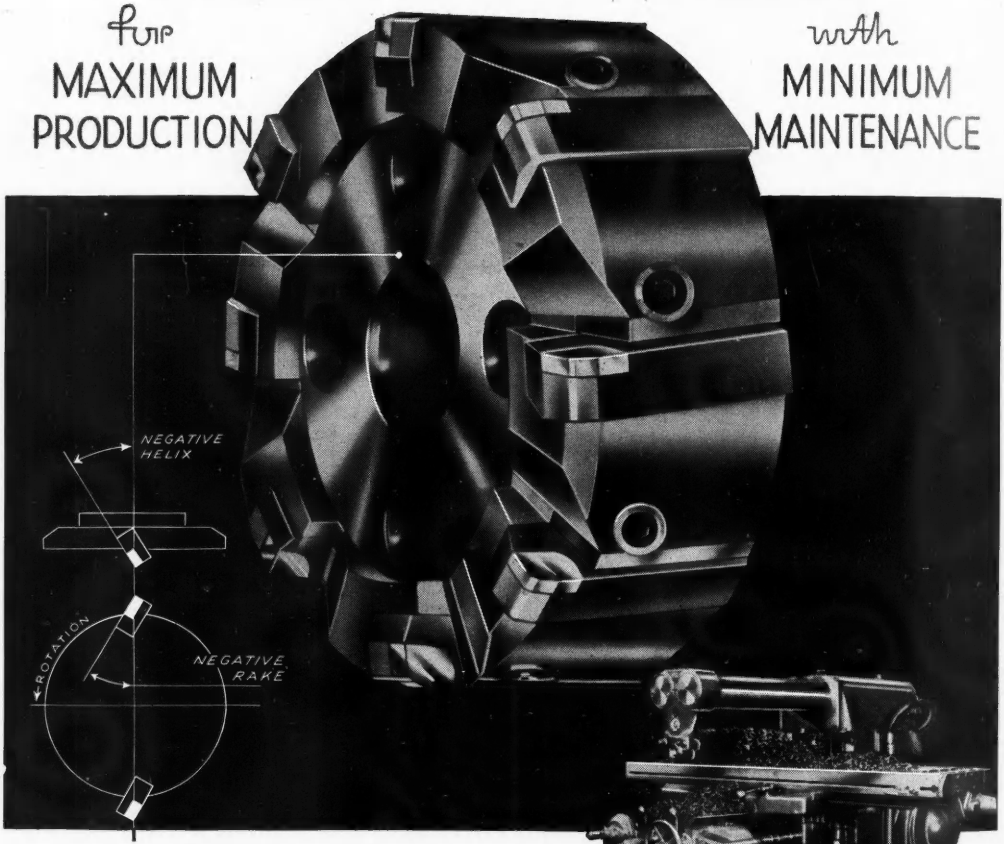

Strong and robust body necessary to withstand the increased pressure involved. Inserted Wimet tipped blades to allow ease of adjustment and to facilitate grinding. Adequate method for rigidly securing blades in position in the cutter body. Maximum chip clearance to promote rapid swarf removal.

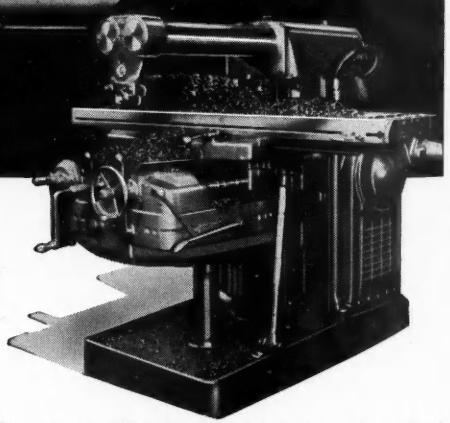

Illustration shows Milwaukee Model 4K fitted with Wimet tipped negative angle cutter after removing 205 cu. ins. of metal from a 90 tons tensile steel die block. The cutter had previously removed 600 cu. ins. of metal from a 50 tons tensile steel billet and was not re-ground between the two operations.

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A NEW ELECTRIC PRESSURE GAUGE WITH A SEMI-CONDUCTIVE MEASURING ELEMENT.

By O. MÜLLER. (From *Archiv für Technisches Messen*, August, 1942).

AMONG the numerous methods used in electric pressure gauges, the method applying semi-conductive measuring elements occupies a fairly important position as it uses D.C. from a portable battery and requires no amplification. These comparatively simple instruments have, however, the disadvantage of being not very accurate, in particular where very slow processes are measured, and of requiring a frequent checking on the calibration curve. In general, they can be used to advantage for dynamic measurements where the calibration curve can be frequently checked, and for outdoor measurements because of their small size.

The instruments using a semi-conductor as measuring element can be divided into two groups: one using resistance elements consisting of one single piece whose resistance changes if the element is compressed or stretched, and one group using resistance elements consisting of a number of thin semi-conductive plates stacked together. The latter elements can, of course, only be compressed and the changes in their resistance are mainly due to changes in the contact resistance between the individual plates. At present the second group is the more reliable.

(1) *Measurements on stacked semi-conductive columns.*

The plates commonly used for these measurements consist mainly of carbon [coal or graphite] and gave to the method the name of "carbon-pressure method." The electrical resistance of a column consisting of individual graphite plates as a function of the pressure applied on this column is shown in Fig. 1. The curve is characteristic for this type of semi-conductor and can often be expressed by a hyperbola equation. The actual values vary, of course, with the material, cross-sectional area, thickness and number of the plates, as well as with the character of the surface.

Fig. 1 represents measurements on a *low*-resistance column consisting of *a large* number of thin graphite plates as used in the instrument described below. As on other occasions *high* resistance columns with a *small* number of plates were used, the reasons for using the *low*-resistance column in this case may be explained more in detail.

While the relation between pressure and resistance hrs been investigated in the past several times, less attention has been paid to the compression of the column. Glamann and Triebnigg found the compression of a graphite column consisting of 10 plates of 1 mm. thickness each to be a linear function of the pressure, once a certain pressure [initial pressure] had been reached. The column used for the tests illustrated in Fig. 1 consisted of 50 graphite plates each 0.18 mm. thick; thus a much larger number of contact surfaces was in operation. It will be seen from curve "*b*" that, to begin with, it is on the contact surfaces that the main compression of the column takes place. If the pressure increases, the sloping of the curve decreases and so does its curvature. It may be assumed that from a sufficiently high pressure onwards the adjoining plates touch one another over their entire contact surface, thus giving the column the properties of one single homogeneous piece, which makes curve "*b*" continue as an approximately straight line.

Measurements were also carried out with a column consisting of three plates of 3 mm. thickness each, made of the same material as the previous column. Tests started from a pressure of 100 g. [400 g in the previous case]—which already gave usuable results. as shown in Fig. 2. Curve "a" drops sharply and, owing to the smaller number of elements, i.e., lower total contact resistance, reaches lower values than the corresponding curve in Fig. 1. Curve "*b*" becomes nearly a straight line at higher pressures, which indicates that the contact between the elements is nearly complete. The compression of this column is only a fraction of the compression of the column of 50 plates, although the total height of both is approximately the same. This confirms that the largest part of the compression is due to the compression at the contact surfaces and only a minor part to the compression of the carbon plates themselves.

(2) *Conclusions for the design of measuring instruments.*

The tests show that columns of semi-conductive plates can withstand only very small pressures. It is therefore seldom possible to apply the pressure directly on the column. This is, usually done for example in the case of accelerometers; in general, however, the pressure is applied to a "shunt" element which is deformed and acts upon the measuring column. In this case, the function of the column is to measure the deformation of the shunt element, rather than the pressure, which is determined only indirectly. While the column is used in this way as an instrument for measuring a length, its main characteristic is now the ohmic resistance as a function of the compression, and not, as previously, the pressure applied to it. Fig. 3 shows this as deducted from the measurements in Fig. 1 for the column consisting of 50 plates. It will be noted that the curvature of the resulting curve is less than that of either curve in Fig. 1.

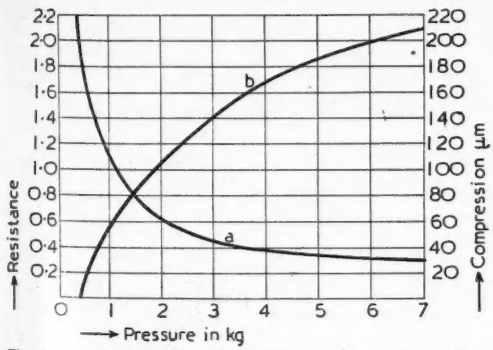


Fig. 1. **Ohmic resistance (a) and compression (b) of a column consisting of 50 thin, semi-conductive plates as a function of the pressure applied to the column.**

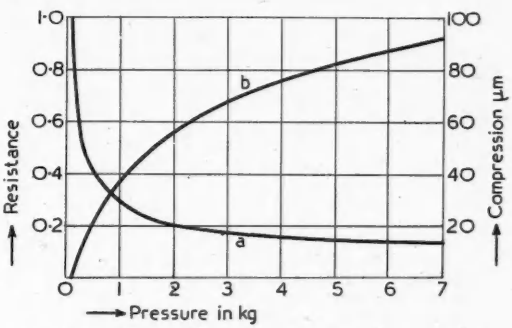


Fig. 2. **Ohmic resistance (a) and compression (b) of a column consisting of 3 thick, semi-conductive plates as a function of the pressure applied to the column.**

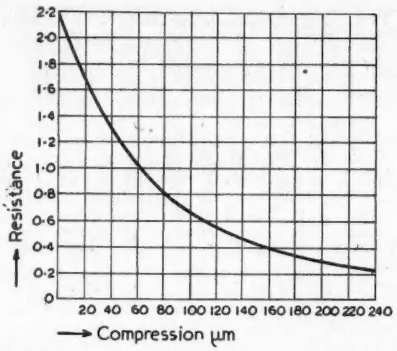


Fig. 3. Ohmic resistance of a column consisting of 50 thin, semi-conductive plates as a function of its compression.

It is often thought that the sensitivity of the column rapidly decreases if the initial pressure is increased. This is not necessarily the case. If the change of resistance is measured by means of Wheatstone's bridge using a deflection instrument, the sensitivity is nearly proportional to $\frac{\Delta R}{R}$, ΔR being the change of resistance within the limits of the variable compression of the column and R the resistance of the column when the bridge is balanced. If, using Fig. 3, the ratio $\frac{\Delta R}{R}$ is calculated for a constant range of change of compression, e.g., 30 μm, and a variable initial compression, the character of the corresponding [central] part of the new curve is but slightly different from the character of the curve in Fig. 3. This is due to the fact that, if the initial compression is increased, both ΔR and R decrease at the same time. On the other hand, in the case of direct pressure measurements [curve "a" in Fig. 1] the ratio $\frac{\Delta R}{R}$ decreases if the initial pressure is increased, though not considerably. If using a pressure shunt, a comparatively high initial pressure can, therefore, be applied to the column without reducing the sensitivity of the instrument as a whole. This is an advantage as a higher initial pressure ensures a more stable mounting of the column, which, in turn, results in a more accurate calibration curve.

It has been shown that the sensitivity changes little over the whole range of Fig. 3, when the initial compression is changed, if only the range of the variable compression to be applied remains constant. But this does not mean that, once the instrument has been set for a definite condition, its calibration curve is a straight line, since although R remains constant, the variable ΔR is not a linear function of the compression. To obtain a straight calibration curve, special arrangements must be resorted to. Connections may be made to give the calibration curve of the bridge a shape which, if combined with the curve of the column, would result in a straight calibration curve for the whole arrangement. Another method is to use two columns and to take differential measurements by increasing the pressure on one and at the same time decreasing it on the other column.

Now the question arises whether to use a column consisting of many or of only a few plates and to determine the most favourable range of compression. Diagrams 1 and 3 on the one, and diagram 2 on the other side, show that a column with a smaller number of plates gives a larger change of resistance for equal compression and for the normal range of initial compression. It is, therefore, more sensitive than the column with a large number of plates, in the case that a compression is to be measured. If, however, the column is used in an accelerometer, where not the compression but the pressure is the deciding factor, a column with many plates may prove superior, as may be seen by comparing curves "a" in figures 1 and 2.

From a purely constructional point of view, it is easier to design an instrument with a column of a few thick plates rather than of many thin plates. But this advantage is more than offset by the accuracy required for the adjustment of the plates and for the plates themselves. If, for example, the terminal faces of the column are not perfectly parallel, the pressure is not evenly distributed over the contact faces of the column but concentrated on a few points and a higher resistance will be measured. On the other hand, a column with a large number of thin plates is softer and adjusts itself more readily. These advantages justify the use of this second type of column in preference to the first type with few and thick plates, the more so as its lower sensitivity can be partly counterbalanced by applying larger deflections, and its mechanical stability increased by a higher initial compression.

As these instruments are mainly used in conjunction with oscillographs with low-resistance loops, it is advisable to use columns of low ohmic resistance, which ensures a better adaptation and thus a better utilization of the energy available on the bridge. A low resistance also limits the errors caused by the heating of the column, as it keeps the development of heat low, without detriment to the sensitivity of the instrument.

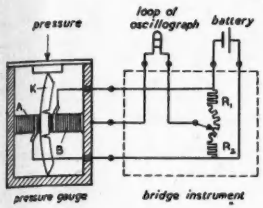
(3) *The differential method.*

This method employing two columns is used if the calibration curve of the instrument is to be a straight line, with the resultant doubling of the measuring effect while incidentally the errors due to heating on the two columns cancel each other out.

When estimating this error due to the heating of the column, it is necessary to take into account not only the relatively favourable temperature coefficient of semiconductors, but also the mechanical construction of the instrument. The fact that the material of the casing and that of the column have different temperature coefficients, influences the initial pressure applied to the column, which results in deviations of the zero-point of the instrument. The more sensitive the column, i.e., the smaller the compression caused by a given pressure, the larger will be the zero-point deviations. Although the influence of the temperature can be mechanically compensated also in single-column instruments, it is preferable to use two-column instruments with columns of a high compressibility, i.e., consisting of a large number of thin plates.

If the differential method is used it is not necessary to confine the range of the instrument to the practically straight part of its characteristic. Instruments using carbon columns are liable to show a certain instability in their zero adjustment and thus favour the use of the largest possible measuring range, where these fluctuations can be neglected to a large extent. Generally, it can be said that it is always preferable to apply the largest possible primary measuring impulses rather than to improve the final indication by a higher sensitivity of the instrument or an increased amplification.

It has been found that it is of advantage to use large variations of the resistance and large travels [compressions]. The travel is, however, limited for dynamic reasons, mainly because an increasing travel causes an undesirable decrease in the natural frequency of the instrument. However, this deficiency can be partly overcome by an appropriate design, and in the following a pressure gauge is described where the natural frequency has been kept sufficiently high while at the same time employing a relatively large travel.



A, B—Carbon columns
K—Bent lever
R_1, R_2—Resistance

Fig. 4. **Schematic diagram of a carbon pressure gauge with bent lever in a Wheatstone's bridge circuit.**

(4) *A new pressure gauge.*

Pressure gauges with carbon columns as used hitherto showed a number of deficiencies which have been largely overcome in the design shown in Fig. 4. The deformation of the intermediate piece, resulting from the pressure under investigation, is not applied directly to the horizontal carbon columns *A* and *B*, but only indirectly through a bent lever *K*. The deflection of the centre of the bent lever causes a compression of the column *A* and an easing of the pressure on column *B*. The bent lever considerably amplifies the deformation of the intermediate pressure part, which allows this to be designed stiff, i.e., to have a very high natural frequency. The ratio of amplification of the bent lever depends on its angle in the neutral position. The lever can, therefore, be designed to suit individual requirements, although in practice the angle is limited by the necessity to maintain a practically constant amplification ratio within the range of the instrument, and consequently a straight calibration curve.

Fig. 4 shows the circuit diagram of the instrument. The columns *A* and *B*, together with the resistances R_1 and R_2 and the potentiometer for zero-point adjustment form a Wheatstone's bridge.

Fig. 5 shows constructional details. The top of the casing *D* is used as the intermediate pressure part whose deformation is, through the lever *K*, transferred to the carbon columns. The pressure to be measured is applied on *D* through a ball. Lever *K* is inserted through an opening in the bottom of the casing which is subsequently closed by a precision screw *V*. The bent lever *K* consists of a single piece, the joints being replaced by incisions which allow for an elastic deflection of the two branches with regard to the central part. When the lever is inserted an initial elastic deformation takes place through which it is held in position. The carbon columns are inserted through two lateral openings. These are closed by the screws *C* which allow the initial pressure on the columns to be easily adjusted. The screws carry the insulated aluminium rod *S* which keeps the carbon plates in position. The mechanical part of the pressure gauge can thus be regarded as one single unit where the disadvantages of loose connections have been entirely eliminated.

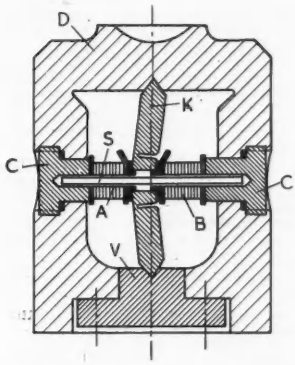


Fig. 5. **Cross-section of the pressure gauge.**

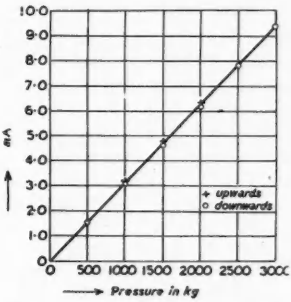


Fig. 6. **Calibration curve of a pressure gauge for a maximum pressure of 3000 kg.**

This pressure gauge can be used for a maximum pressure of 3,000 kg.; Fig. 6 shows the corresponding calibration curve which is practically a straight line. The constancy of the calibration curve is good and the errors due to variations in the temperature proved sufficiently small over a wide range.

THE INFLUENCE OF LIQUIDS UPON THE STRENGTH OF GLASS & HARDENED STEEL.

By C. Benedicks and G. Ruben. (From *Jernkontorets Annaler*, Vol. 129, 1945, pp. 37-106).

It is an old concept that the strength of a material for a given type of stress depends entirely upon the properties of the material itself. There exists, however, evidence that the surrounding medium may also be of considerable influence in this respect. It is, for instance, known that glass may be "cut" under water. This would seem to imply that the production of the line of fissure requires less stress when the glass is wetted than when it is dry.

In 1931 the Metallographic Institute was requested by the Power Plant Department of the Royal Hydraulic Power Commission to investigate the cause of the fracture of certain large bolts of the shaft coupling of a hydraulic turbine at the Trollhaettan power plant. This bolting was made of a steel containing 0.27 C.; 0.67 Ni; 0.23 Cr. The material was found to be homogenous and properly heat treated. There was some evidence that clean water from the cooling air intake had wetted the bolting. This fact was thought to be a contributory factor in the formation of cracks in the bolts subjected to static stress. A special test was made to investigate this point, and it was found that the ultimate tensile strength of the material was 92.2 kg. per sq. mm. when it was dry and 90.4 kg. per sq. mm. when it was wetted. This shows that the strength of the material was reduced by 2 per cent in the presence of moisture.

An investigation into the influence of water upon the fatigue strength of a stainless steel (0.35 C; 13.0 Cr) was conducted by the ASEA company in 1933. This material was quenched from 900 deg. C. in oil and then tempered at the temperatures given in Table I. Both smooth and notched test bars were examined, and both oil and sea water were used as wetting agents. From the results given in Table I. it will be seen that the fatigue strength of the notched test bars decreased by 14 to 6 per cent when the pieces were wetted with water instead of oil; while the decrease in fatigue strength of the smooth test bars ranged from 60 to 40 per cent.

TABLE I.—Fatigue Strength of 0.35 C—13.0 Cr Steel based on 2 Million Stress Cycles.

Tempering Temp. deg. C.	600			650			700			800		
	oil	water	Red. per cent	oil	water	Red. per cent	oil	water	Red. per cent	oil	water	Red. per cent
Smooth test bar	45.5	19.5	57.2	42.0	20.0	53.5	37.5	19.0	49.4	30.5	19.0	37.8
Notched test bar	18.5	16.0	13.5	18.5	16.5	8.3	17.5	16.5	5.7	17.5	16.0	7.7

Considering that this is a stainless material, the diminution in fatigue strength cannot be attributed to the occurrence of corrosion fatigue.

In order to exclude any possibility of corrosion, and also to ensure homogeneity of the material tested, experiments were carried out in 1935 with the use of ground and polished glass 2.2 mm. thick. These tests were conducted by C. Benedicks and P. Sederholm, and have not been published heretofore. It was found that the breaking strength of glass wetted by water is 38 per cent below that found in air. With a 10 per cent aqueous solution of NaOH the respective diminution in strength was 33.8 per cent.

A series of tests on steels of various compositions was made in the laboratories of the ASEA company in 1935. The following results were obtained.

TABLE II.—Fatigue Strength of Steels.

	Smooth test bar			Bar with round notch			Bar with V notch		
	oil	water	change per cent	oil	water	change per cent	oil	water	change per cent
Carbon steel, 0.46 C 0.29 Si, 0.74 Mn normalised	29.0	15.0	−48.0	21.3	12.0	−43.6	14.0	—	—
Cr Ni steel, 0.24 C 0.25 Si; 0.55 Mn 2.95 Ni, 0.62 Cr normalised	34.5	17.0	−50.8	24.5	14.5	−40.8	15.5	—	—
Nitriding steel Bofors AR 0.23 C 0.48 Si, 04 Mo 1.6 Cr, 1.2 V	37.0	18.5	−50.0	26.5	17.5	−33.9	17.0	11.0	−35.3
do nitrided 35 h at 520 deg. C.	54.0	44.0	−18.5	58.0	41.5	−28.4	45.0	34.5	−23.4
Special cast iron 3.32 C, 1.09 Si, 0.50 Mn	11.0	8.5	−22.7	—	—	—	9.0	—	—

The most recent investigation of the problem was made by C. Benedicks in 1942/43 for Uddeholms A.B. The tests were carried out on both glass and hardened steel with the use of a Chevenard micro-tester. With regard to glass it was found that its bending strength in water averages some 76.7 per cent of that recorded in air. Similar tests made with kerosene as wetting agent showed that this medium improves the bending strength of glass by some 16 per cent as compared with air. When toluol was used as wetting agent, the bending strength of the glass was found to have increased by 11 per cent. A Rumanian spindle-oil was found to improve the bending strength by 9 per cent, and a coal tar base lubricating oil gave an improvement of as much as 30 per cent.

In order to study the wetting effect which must be held responsible for the variation in the strength of the wetted material, a number of tests were made in which the influence of mercury upon the bending properties of zinc bars of 4 mm. diameter was examined. It was found that the angle through which the bars wetted by mercury could be bent without breaking, averaged only 8.6 per cent of the angle obtaining in air.

The following steels were then examined:

R Hardened centreless ground steel rounds of 2 mm. dia. supplied by Uddeholms A.B. 1.2 C; 0.24 Si; 0.27 Mn; 0.09 Cr.

W2—W6 Steel strip supplied by John Wall A.B.

	W2	W3	W4	W5	W6
Thickness, mm.	1.0	1.0	1.0	2.0	1.0
Width, mm.	10	10	10	10	10
C, per cent ..	0.73	0.74	0.75	0.78	0.75
Si, per cent ..	0.34	0.29	0.34	0.25	0.31
Mn, per cent ..	0.40	0.43	0.44	0.44	0.45
P, per cent ..	0.017	0.046	0.03	0.018	0.0222

U Munkfors steel strip. Hardened and tempered at 840 deg. C. in muffle, cooled between water cooled platens. 0.83 C; 0.16 Si; 0.34 Mn.

From the large number of observations made it was found that water decreases the strength of steel by some 22 per cent, while wetting by aliphatic hydrocarbons and by such materials as anti-corrosion oil and lubricating oil actually increases the strength as compared to the strength recorded in air. In some cases the increase may amount to as much as 30 per cent. By way of example, ethyl alcohol decreases the strength by 13 per cent, but kerosene increases it by 27 per cent. Benzine, hexane, and heptane cause increases in strength by 18, 17, and 12 per cent respectively. Solar oil causes an increase in strength by 18 per cent. A Rumanian spindle oil distillate improved the strength by only 2 per cent, but a spindle oil raffinate produced an increase by 29 per cent.

THE INFLUENCE OF PRE-MAGNETISATION ON THE TIME OF RESPONSE OF RELAYS.

By H. Mutschke. (From *Zeitschrift für Fernmeldetechnik, Werk-und Gerätebau,* No. 11, Nov. 11th, 1942, pp. 170-171)

It has been proved that the time of response of a D.C. relay is not affected if other relays are connected in parallel with it as shown in Fig. 1, provided that the time constant of the circuit remains unchanged.

This could lead to the assumption that also if the relays are arranged according to Fig. 2 the switching time of relay R_1 is not affected by the relay or relays R_2 as both relays are connected to the same constant pressure U. This, however, is not true. Let it be assumed that R_1 is a light relay with about 300 ampere-turns and that R_2 are heavy relays with about 1500 ampere-turns each. If the time of response of R_1 is plotted against the number of relays R_2 connected in

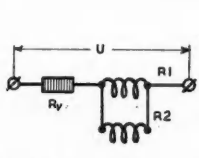


Fig. 1. **Two relays connected in parallel, with common series resistance.**

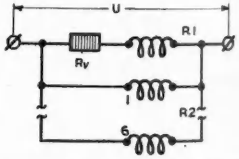


Fig. 2. **Relay R1 with series resistance, connected in parallel with Relays R2.**

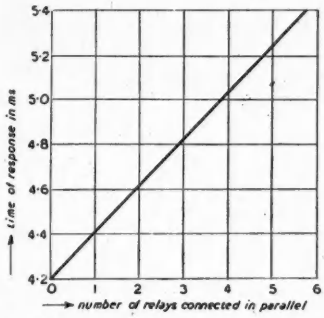


Fig. 3. **Time of response of R1 connected according to Fig. 2, as a function of the number of relays R2 connected in parallel with it.**

parallel with it, the diagram in Fig. 3 results, which shows that the time of response of R_1 increases by 35 per cent if six relays R_2 are connected.

This increase of the time of response is explained by the pre-magnetisation of relay R_1 which is due partly to the remanent magnetism of the core of R_1 and partly to the extra pressure which occurs at the moment of disconnection of the relays. This extra pressure can reach fairly high values which, of course, also depend on the disconnecting speed (Fig. 4). As there is always

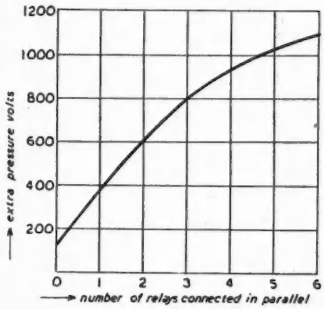


Fig. 4. **Extra pressure as a function of the number of parallel relays R2.**

some remanent magnetism if the core has not been demagnetised by a reversed magnetisation current, the extra pressure can either increase or decrease the remanent magnetism, depending on the polarisation of the core. [If the core is neutral the extra pressure will bring about a magnetisation which will leave behind a remanent magnetism]. If the remanent magnetism is increased the time of response is shortened, while the releasing time increases. The effect is reversed if the remanent magnetism is weakened or reversed by the extra pressure. This effect can be utilized if the relay is fitted with an auxiliary winding giving it a pre-magnetisation which the extra current either increases or decreases. The release time is thereby either increased or shortened (Figs. 5 and 6).

The effect described above is also the cause of the increase of the time of response of relays connected in parallel according to Fig. 2. Taking the characteristic in Fig. 3 as an example, the time of response of relay R_1 at the first impulse is 4 ms. If the relays are subsequently disconnected, a self-inductive e.m.f. is created which as such is reverse to the initial pressure applied to the relays. This produces a current which demagnetizes the relays and may give it even a reverse

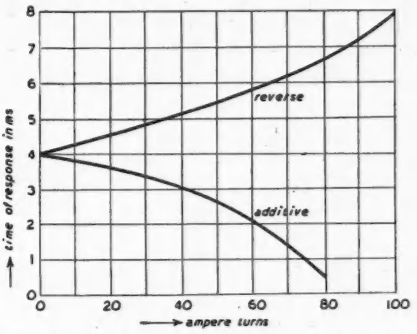


Fig. 5. **The influence of the pre-magnetisation on the time of response of a relay.**

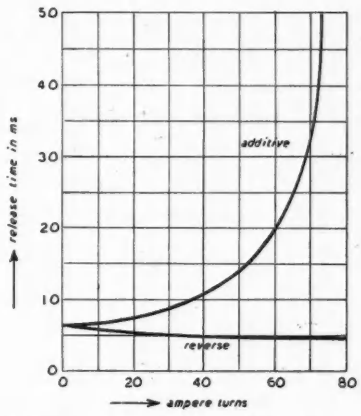


Fig. 6. **Release time of a relay after additive or reverse pre-magnetisation.**

pre-magnetisation. This has to be overcome at the next switching operation and thus delays the action of the relays. That the counter-current can reach a considerable magnitude will be seen from Fig. 7, which represents an oscillogram of the current flowing through R_1 if just one relay R_2 is connected in parallel. The comparatively long duration of the counter-current should be noted.

The conditions described above can lead to complications where only short impulses are applied to R_1, which in turn builds up a holding circuit energising R_2. If the impulse duration is of the order of the response time of R_1, the entire arrangement will operate only every other time.

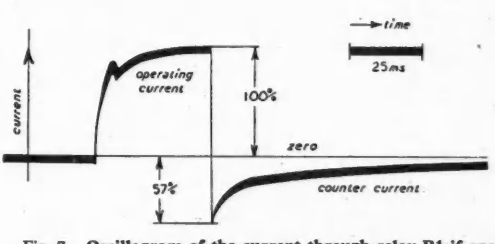


Fig. 7. **Oscillogram of the current through relay R1 if one relay R2 is connected in parallel with it.**

The reason for this failure is that the limited energy of the impulse is insufficient to reverse the magnetisation of the relay R_1, which thus cannot respond. When the next short impulse occurs, the relay R_1, which through the first impulse had regained its normal magnetisation, responds in the normal way and the parallel relays are energised.

This difficulty can be overcome if the connections are made according to Fig. 8, where the switching of the relays R_2 is effected by R_1 through a contact ; to reduce the extra current the relays R_2 are shunted, which, of course, alters their release time.

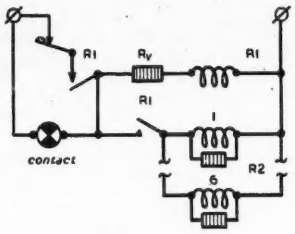


Fig. 8. Connection avoiding the influence of the pre-magnetisation of R2.

AUTOMATIC PROTECTION OF POTENTIAL TRANSFORMERS.

By K. WIDMER. (From *Oerlikon Bulletin*, No. 250, July/August, 1944, pp. 1614-1618).

THE protection of potential transformers in high voltage networks has always proved difficult, none of the usual protective devices giving satisfaction. The simplest and most widely applied protective measure consisted in the use of fuses, but owing to its small diameter the fuse wire was attacked by the corona effect and finally destroyed. Moreover, a melting of the fine fuse wire may even be caused by the charging current.

The protective device for potential transformers built by the Oerlikon Company combines a protective resistor with a switch equipped with thermal tripping device. By utilizing the heat generated in the protective resistor for actuating the tripping, the tripping current may be chosen as low as the max. continuous current that can be carried by the potential transformer without damage. The resistance of the protective device is so chosen that under normal conditions the short circuit current is limited to a few amperes which can be safely interrupted by the switch, yet the accuracy of the transformer is not affected.

The tripping characteristic of a typical switch of this type for 50 kV. is shown in Fig. 1. Here it is seen that the limiting current which leads to tripping after one hour amounts to 0.07 amp. This value is in excess of the current consumption of potential transformers in star connection, and tripping will not, therefore, take place in the event of a ground fault. This is especially important in networks equipped with earth coils.

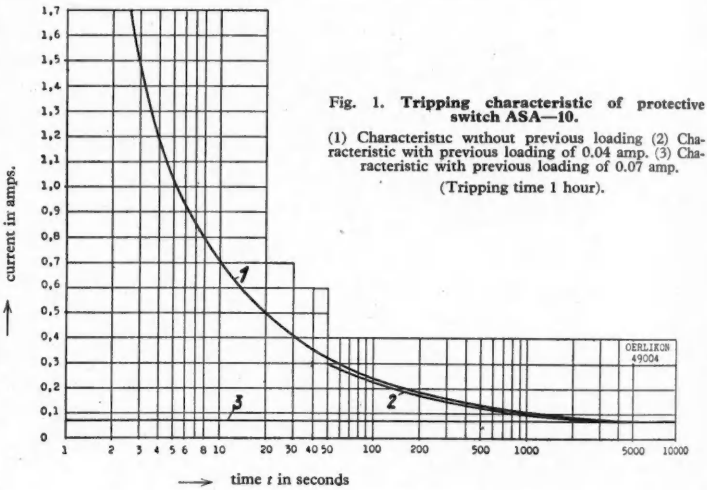


Fig. 1. **Tripping characteristic of protective switch ASA—10.**

(1) Characteristic without previous loading (2) Characteristic with previous loading of 0.04 amp. (3) Characteristic with previous loading of 0.07 amp.

(Tripping time 1 hour).

The design features of this protective device are shown in Figs. 2 and 3, where Fig. 2 shows the type employed for voltages up to 30 kV. and Fig. 3 refers to the type supplied for voltages of 50 and 60 kV. The way in which the 60 kV. type is usually mounted for outdoor use is illustrated in Fig. 4. But it may also be mounted upon the potential transformer itself. For higher voltages, such as, for instance, 150 kV., the device is mounted on insulators of a special type.

The resistor of the device consists of a wire coil placed in an oil filled cylindrical container of insulating material. This container is closed at the top by an elastic diaphragm. When filling the container with oil a small air space is left below the diaphragm. In operation the heat generated by the resistor oil will compress the air in this space, thus exacting a pressure upon the diaphragm. If the deflection of the latter exceeds a pre-determined value, the tripping device is released and the switch opens. In the type shown in Fig. 3 a suitable braking device is incorporated which secures opening of the switch without undue shock.

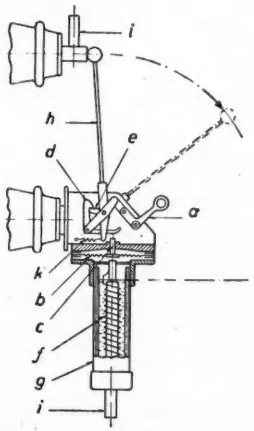
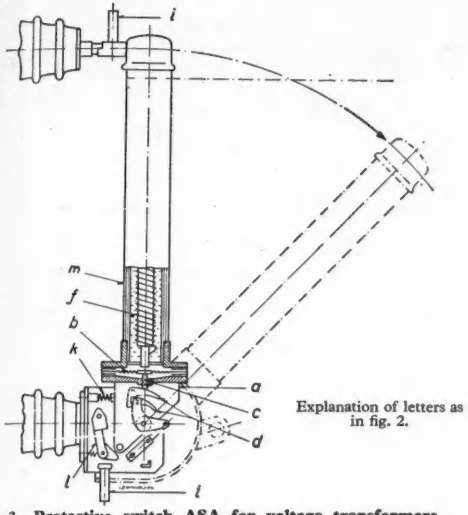


Fig. 2. **Protective switch ASI for voltages of 6-30 kV.**

(a) Operating gear
(b) diaphragm
(c) Release pin
(d) Catch
(e) Lever
(f) Resistor
(g) Tube of insulating material
(h) Switch-rod
(i) Terminals
(k) Spring
(l) Brake
(m) Tube of insulating material serving as switch blade



Explanation of letters as in fig. 2.

Fig. 3. **Protective switch ASA for voltage transformers for 45-60 kV.**

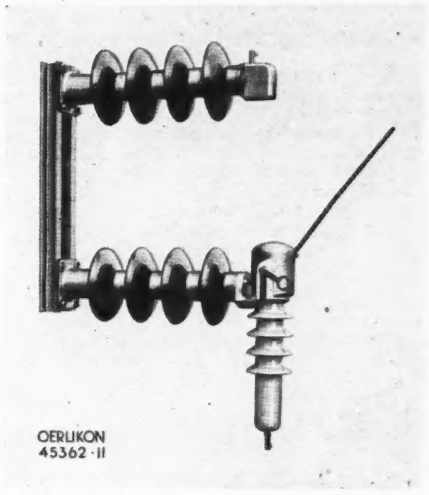


Fig. 4. **Protective switch ASF for outdoor installation.**

NEW VOLTAGE REGULATOR FOR BATTERY CHARGING.

By SZEKELY MIKLOS. (From *Elektrotechnika*, Budapest, 1st March, 1944, pp. 63-67).

THIS paper describes a new system of regulation in which an A.C. regulator is used to regulate the D.C. charging current of a battery. This includes a description of the Ganz-Ratzovsky regulating system and a special " converter " controlling the regulator.

The charging current required for a battery varies and it is of considerable advantage to control this current by the voltage on the battery leads. The voltage regulator of the charging set described is controlled by the battery voltage and feeds the rectifier with the correct charging current.

It was necessary to design a new circuit element to enable the control of the A.C. voltage regulator to be carried out by D.C. This new device, the " converter," is basically a rectifier bridge. Between the A.C. connections of this bridge, which lead to the voltage regulator, and the D.C. connections of it leading to the battery, there is a fixed relationship. The A.C. voltage will change in proportion to the changes of the D.C. voltage of the rectifier bridge.

The charging set consists of the following circuit elements : A.C. voltage regulator, main rectifier and the voltage regulator control device, the converter (aux. rectifier). Fig. 1 shows the external connections of these circuit elements, Fig. 2 shows the circuit diagram.

The main rectifier is fed by a transformer (T), and the rectifier output is smoothed by a choke (Z). Smoothing is only necessary when the battery load is sensitive to the interference caused by the A. C. ripples.

THE CIRCUIT ELEMENTS.

The voltage regulator. A Ganz-Ratzovsky type of voltage regulator was used, but the use of an A.C. voltage regulator of different manufacture is also possible. The circuit diagram of this voltage regulator is shown in Fig. 3, its main components are : a small Ferraris motor, a switching element and a group of transformers. The rotor movement of the motor is controlled by the torque of two opposing magnetic fields from two different coils. At a certain predetermined voltage these fields are cancelled out and the rotor stops moving. If the

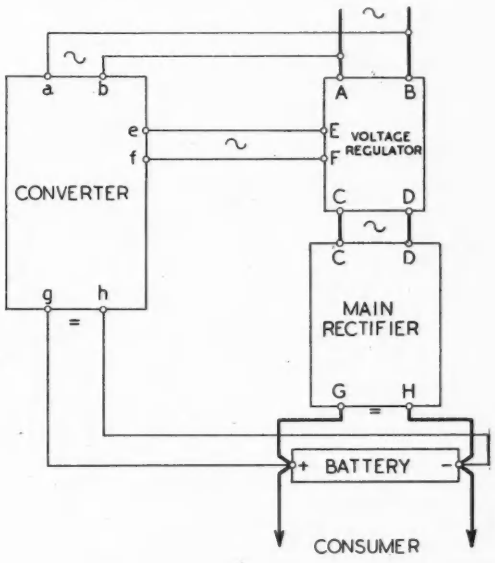


Fig. 1. **External connections of the battery charging set circuit elements.**

voltage on the battery leads change, the Ferraris rotor disc starts moving and switches on or off the sections of the transformer included in the voltage regulator, so that the correct charging current is supplied to the battery. Voltage variations of ± 20 to 25 per cent are necessary in order to provide the correct charging current at any time during the charging process.

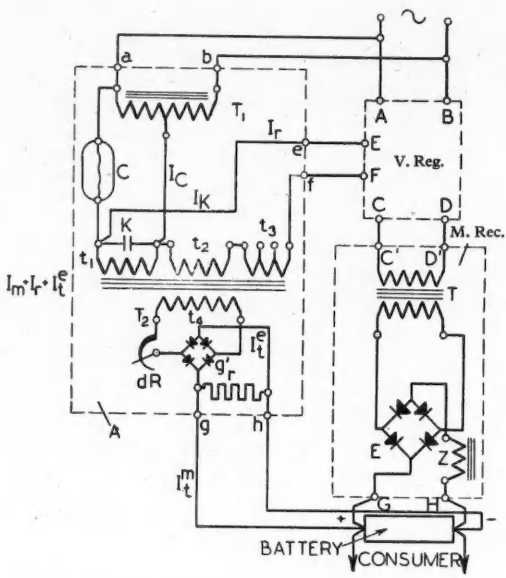


Fig. 2. **Circuit diagram of the battery charging set.**

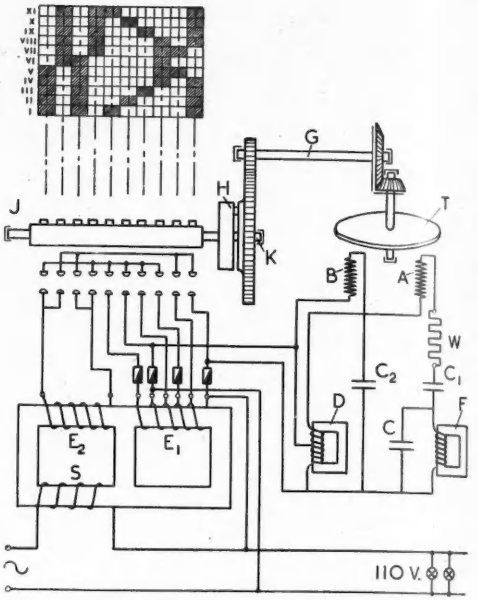


Fig. 3. **Circuit diagram of a standard single phase Ganz Ratzovsky type voltage regulator.**

The converter unit. The circuit diagram of this unit is shown in Fig. 2. The winding t_1 of the primary of the transformer T2, is fed through a current regulating (iron-hydrogen resistance) valve C from an autotransformer T1. The secondary winding of transformer T2 is connected through an adjustable resistance dR to the A.C. side of the rectifier bridge. The battery leads are connected to the D.C. side of the rectifier and the current drain of the converter unit from the autotransformer is practically independent of voltage fluctuations on the mains and of load. Current supplied by this unit to the battery is only influenced slightly by the battery voltage. There is a fixed relationship between the voltage on the D.C. side (battery leads) and A.C. side (secondary of transformer T2) of the rectifier bridge; any change in the battery voltage, therefore, causes a proportional change in the voltage on the secondary of T2, which is transmitted by the primary of this transformer to the voltage regulator. All the adjustments necessary are then made by the Ferraris motor. The turns of t_2 and t_3 are chosen to suit the requirements of the voltage regulator.

A condenser C is embodied to increase the sensitivity of the converter unit.

The relationship between the battery voltage and the A.C. voltage on the secondary of the transformer T2 can be changed by adjusting the resistance dR. It is thus possible to increase or decrease the charging current, to suit the current requirements of the particular types of battery to be charged.

A ballast resistance, which serves as a load, is included in order to prevent over-charging of the battery, caused by the small charging current, which keeps on flowing when the battery is fully charged.

THE ELECTRIC VARIABLE-SPEED DRIVE OF MACHINE TOOLS.

By M. STEINEBRUNNER. (From *The Brown Boveri Review*, Vol. 31, No. 8, August, 1944, pp. 251-260).

MODERN machine-tools are required to operate economically and accurately, to be readily controlled, and to be designed for as many machining operations as possible. For the design of their drive an idea must first be obtained of the pressures, torques, speeds, and motions occurring during the different working processes. Much valuable practical experience has been collected on this subject. The values so obtained, when plotted in the form of curves, give the machine designer a clear and sufficiently accurate idea of the conditions which a machine-tool has to fulfil.

During a working process the motion of the tool and work is either linear or rotary, while frequently the two movements are coordinated. In some such cases the rates of motion of the individual parts may have to be adjustable within a wide range and in others varied progressively or in steps. A number of simple examples will serve to illustrate this point.

In the case of a lathe it must be possible to vary the spindle speed in order to obtain the most satisfactory cutting speeds for various materials and any diameter of the work-piece. Moreover, where face lathes are concerned the adjusted spindle speed increases with diminishing diameter of the work during the machining process. In the case of planing machines the table motion is split up into cutting and return strokes. Both movements entail a wide range of adjustment and follow each other so closely during the working process that several thousand reversals may take place per hour.

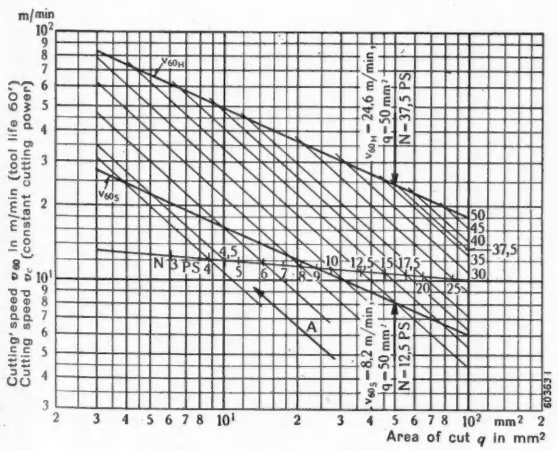
The practice for some considerable time past has been to provide electrical individual drives to impart the motion to the various machine-tool components. This splitting up of the driving power is by no means restricted to large machine tools, even small machines now having separate work-spindle, feed-spindle, and coolant pump drives. In other words, there is a distinct tendency to locate the driving motor closer and closer to the shaft to be driven and to dispense with mechanical power transmission gear as far as possible, with the result that the design of the machine becomes simpler while its productivity is increased. This design desideratum, however, cannot always be correctly realized,

especially when the revolutions of the driven shaft have to be adjusted within wide limits or varied during the machining process. *It was not until the advent of the electric stepless variable-speed drive that arrangements which are superior to the conventional layout with single- or multi-speed motor and step gear, could be found to meet such requirements*, although where particularly wide speed ranges are concerned step gear cannot entirely be dispensed with.

In order to be able to get the most out of a machine-tool it must be possible to adjust the different speeds to the value best suited to each machining operation which may have to be carried out on the machine in question. If in the case of a step-gear drive this value falls between two gear ratios the revolutions have to be reduced to the next lower speed step, thus correspondingly reducing production. Assuming, for instance, a gear ratio of 1 : 2 production may drop by as much as 50 per cent. With a stepless variable-speed drive, however, the most suitable revolutions are invariably attained.

The electric stepless variable-speed drive, the motor of which delivers a constant torque over the entire speed range, affords an advantage to which little attention has hitherto been paid. Assume that such a drive is employed for a lathe on which high-speed and super-hard alloy tools are employed. The double logarithmic diagram in Fig. 1 shows the cutting speeds $V_{60\,S}$ and $V_{60\,H}$ corresponding to a tool life of 60 minutes in relation to area of cut for turning steel having an ultimate strength of 42 kg./mm². with high-speed and super-hard alloy tools. (Life of tool = machining time after which edge is dulled). Apart from these two curves others are given for the cutting speeds V_c with constant cutting power. These are the straight lines running at about 45 deg., whereas the characteristics of the two cutting speeds V_{60} are somewhat flatter. From the points of intersection of the two families of curves and interpolating, the cutting power for any area of cut when turning with high-speed steel or super-hard alloy tools, can be determined. If the cutting speeds and powers for turning with super-hard alloy and high-speed steel tools are compared it will be seen that, referred to the *same* area of cut, the values for super-hard cutting alloys are about three times higher than the corresponding values for high-speed steel. Since the cutting power varies in direct proportion to the cutting speed the torque is the same for both super-hard alloy and high-speed steel tools, assuming the same cut dimensions. This signifies that, based on the lowest motor speed, the speed box of the lathe should be laid out for machining with high-speed steel and the various ratios selected for the torques occurring when high-speed steel tools are employed. When working with superhard alloy tools the revolutions given by the gear ratio selected for turning with high-speed steel, will be regulated upwards by the constant-torque variable-speed motor until the desired speed is attained. This increase in revolutions is readily permissible on the lower speed steps, whereas in the upper range the wheels of the gearing must be correspondingly proportioned. In this way the constant-torque variable-speed drive can be fully utilized and the productivity of the lathe substantially improved. In other words, as may be inferred from the above considerations, only the *constant-torque variable-speed drive* permits of economic operation with super-hard alloy tools, in that it enables cuts of large area to be turned at an increased cutting speed, whereas with a constant-power variable-speed drive the area of the cut must be diminished. Proof of this is furnished by Fig. 1. Compare, for instance, the product of the area of cut and the cutting speed when machining with super-hard alloy tools, for a cutting power of 12.5 and 37.5 h.p. The difference in the cutting rates is about 1 : 3.8 in favour of the constant-torque variable-speed drive.

The following table (see p. 206) shows the *speed range and torque or power characteristic of the more important electric stepless variable-speed drives* now available, as well as the type of drive coming into consideration for a definite duty. The final choice of a drive, however, also depends on other factors, apart from speed range and torque or power characteristic, as will be evident from the following example of speed variations within wide limits, illustrated on the basis of Fig. 2. *Example*: Assuming an initial power of 0.2 h.p. at 80 r.p.m. let it be required progressively to adjust the revolutions of a spindle to any value within a speed range of 80-6000 r.p.m. For reasons of design and manufacture a stepless variable-speed drive *A* with a speed range of 400-4800 r.p.m. was selected. These speeds are reduced to 200-2400 r.p.m. through a pair of wheels *B* having a


m/min
Cutting speed v_{60} in m/min (tool life 60') Cutting speed v_c (constant cutting power)
Area of cut q in mm²
v_{60H}
v_{60S}
v_{60H} = 24.6 m/min
q = 50 mm²
N = 37,5 PS
v_{60S} = 8.2 m/min.
q = 50 mm²
N = 12,5 PS
A
N 3 PS 4 4,5 5 6 7 8 9 10 12,5 15 17,5 20 25 30 35 40 45 50 37,5
60561

v_{60H} Characteristic for machining steel having an ultimate strength of 42 kg/mm² with super-hard alloy tools.

v_{60S} Characteristic for machining steel having an ultimate strength of 42 kg/mm² with high-speed steel tools.

A. Inclination of characteristic lines of cutting speeds v_c for constant cutting powers.

Example : Machining of steel as above. Selected area of cut q = 50 mm².

Values obtained :

(a) When employing high-speed steel tools :

Cutting speed v_{60S} = 8.2 m/min. cutting power N = 12.5 H.P. (metric).

(b) When employing super-hard alloy tools :

Cutting speed v_{60H} = 24.6 m/min. cutting power N = 37.5 H.P. (metric).

Fig. 1. Diagram showing the relation between the cutting speed v_{60} (tool life 60 min.) and cutting speeds v_c for constant cutting powers as a function of the area of cut q when turning steel having an ultimate strength of 42 kg/mm² with high-speed steel and super-hard alloy tools.

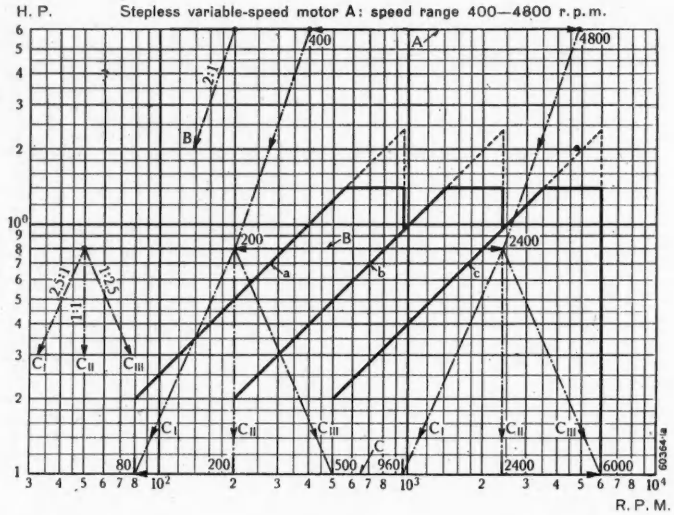


Fig. 2. **Speed and power diagram of a variable-speed drive for 80-6000 r.p.m. with variable-speed Ward-Leonard-controlled d.c. motor and speed change gear.**

Ward-Leonard-controlled motor A, speed range 400-4800 r.p.m. Gearing B for speed reduction in range 2:1. Three-speed change gear C. Initial speed range 200-2400 r.p.m.

Step C_I = Speed reduction in ratio 2.5:1. Step C_{II} = Ratio 1:1. Step C_{III} = Speed increase in ratio 1:2.5.

N. Power in H.P., n = R.P.M.

a. Power characteristic when varying speed of d.c. motor between 400 and 4800 r.p.m. and employing step C_I of speed change gear. Speed range 80-960 r.p.m., power 0.2-1.4 H.P.

b. do. for step C_{II}, speed range 200-2400 r.p.m. power 0.2-1.4 H.P.

c. do. for step C_{III}, speed range 500-6000 r.p.m. power 0.2-1.4 H.P.

The ordinates of the —— · —— lines have no signification.

Current system	Drive		Speed range	Torque or power constant
A.C.	Squirrel-cage motor with asynchronous pilot generator (for high speeds)		up to approx. 1:4	Torque
A.C.	Shunt commutator motor		up to about 1:12	Torque
D.C.	Shunt-wound motor		up to about 1:4	Power
D.C.	Ward-Leonard-controlled motor	Voltage regulation	up to about 1:20	Torque
D.C.	Ward-Leonard-controlled motor	Mixed regulation i.e. first voltage then field regulation	up to about 1:40 and over	In lower part of range torque; in upper part power
D.C.	Booster-controlled motor	Voltage regulation, possibly mixed regulation, i.e., subsequent field regulation	up to about 1:40 or over	Torque; in upper part of range possibly power

ratio of 2 : 1. Following these wheels there is a speed change gear C with a first reduction stage C_I of 2.5 : 1, a second stage C_{II} with a ratio of 1 : 1, and a third speed-increasing stage C_{III} with a ratio of 1 : 2.5. On step C_I the spindle revolutions can be infinitely varied between 80 and 960 r.p.m. on step C_{II} between 200 and 2400 r.p.m., and on step C_{III} between 500 and 6000 r.p.m. These ranges overlap quite considerably, which, however, is even of advantage, in that for scraping or finishing cuts and low power requirements the upper stages of the step gear can be employed, and for the roughing cuts the lower stages. Referring to the foregoing table both shunt commutator and d.c. Ward-Leonard-controlled motors can be designed for a speed range of 1 : 12. In the present case, a Ward-Leonard-controlled d.c. motor was selected, although this drive is more expensive than a shunt commutator motor. The deciding factor here, however, was the fact that a d.c. motor can run much faster than a shunt commutator motor and is thus substantially smaller and lighter than the latter.

A number of practical examples will now be given to show how driving problems can be advantageously solved by employing electric stepless variable-speed drives.

On the rigid milling machine depicted in Fig. 3 work-pieces are milled by the hydraulic copying process. In as much as it was hitherto impossible to mill light metals by reason of the fact that the high milling speeds involved were unattainable, it was decided to design a special high-speed milling spindle drive for this application. As driving unit a three-phase squirrel-cage motor was selected, this being embodied in a special milling head. The motor shaft, the revolutions of which can be progressively varied from 4000 to 15,000 r.p.m., also serves for carrying the milling cutter. The three-phase supply at variable frequency, necessary for speed varia-

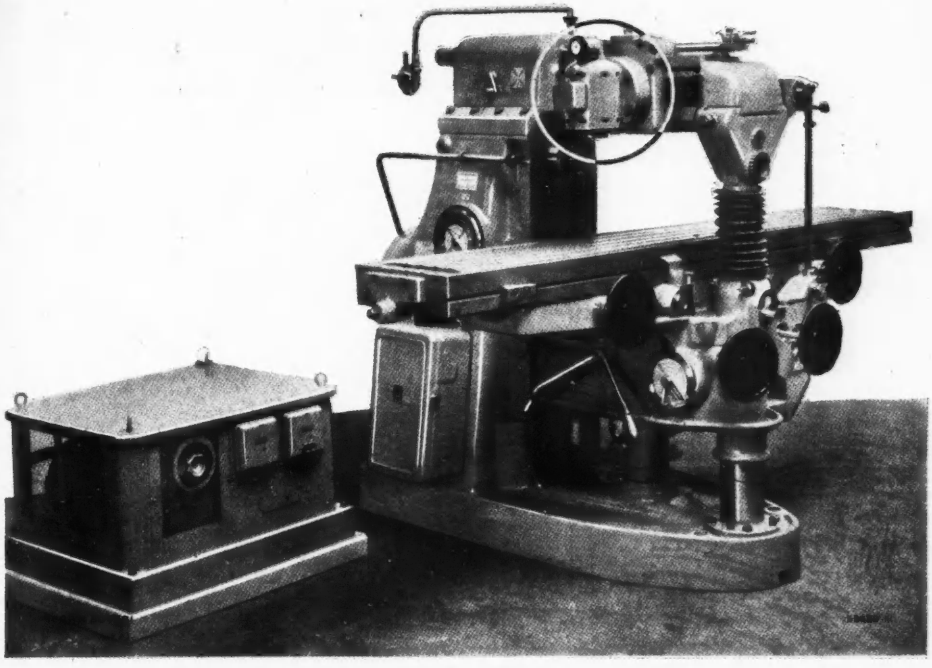


Fig. 3. **Light-metal milling spindle drive for a rigid milling machine, speed range 4000-15,000 r.p.m.**

Speed variation is achieved by changing the frequency. The high-speed milling spindle head can be rapidly substituted for the conventiona milling head. Alongside the machine is the variable-speed frequency changer with shunt commutator motor drive and associated control gear

tion purposes, is provided by a self-contained frequency changer set. The asynchronous pilot generator for feeding the squirrel-cage motor is driven by a three-phase shunt commutator motor. Through variation of the speed of this motor the frequency of the pilot generator and in consequence the revolutions of the squirrel-cage motor are regulated. The handwheel on the shunt commutator motor serves to adjust the desired revolutions of the high-speed milling spindle. Due to the high motor speed the high-speed milling head is even lighter than the conventional milling head and they can be rapidly interchanged at any time. *The drive is thus of extremely simple and appropriate design and forms an interesting example of the manner in which the working range of a machine-tool can be extended by means of a well-adapted, stepless variable-speed drive.*

Turret lathes operate most economically if the spindle revolutions can be regulated to the most favourable cutting speed for the work and tool and are capable of rapid variations when the tool is changed or the diameter of the workpiece alters. Fig. 4 shows a self-contained driving and control set for a turret lathe. The three-phase shunt commutator motor has a speed range of 430-2150 r.p.m., stepless speed variation being achieved by shifting the brushes. This large speed range enables the conventional speed change gear to be dispensed with, thus rendering the design of the lathe simpler and reducing transmission losses. The *single-lever control* employed on this lathe for the first time merits particular attention (see diagram in Fig. 5). By variation of the stroke of one single lever the shunt commutator motor can be started or stopped in one direction or the other, and adjusted to the desired revo-

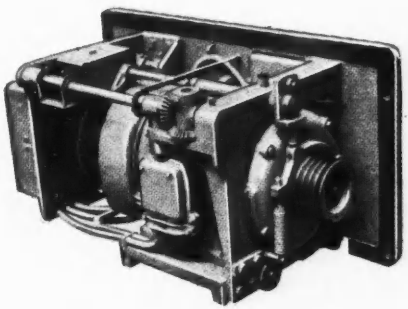


Fig. 4. **Self-contained driving unit comprising shunt commutator motor and control and protective equipment for single-lever operation, in design for flush-mounting in the base of a turret lathe.**

lutions. Since in this manner the motor can be changed from one direction of rotation to the other or stopped, the lathe is particularly suitable for work involving rapid reversal of the spindle. Certain operations on this lathe entail up to 600 reversals per hour. *The simple and ingenious control gear gives the shortest possible setting-up and manipulating times and, as carefully conducted tests have proved, increases production by at least 30 per cent over turret lathes with conventional drives.*

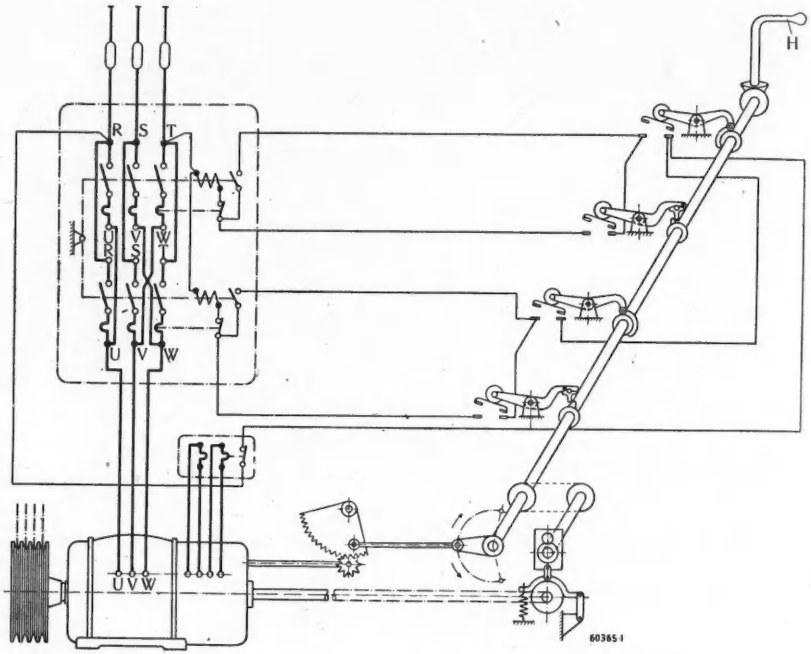


Fig. 5. **Diagram of Brown Boveri single-lever control for shunt commutator motors.**

By deflecting lever H to one side or the other the shunt commutator motor is started up in one direction or the other and its revolutions varied. Returning of the lever to the zero position results in disconnection, mechanical braking and blocking of the motor.

With the *centreless grinding machine* depicted in Fig. 6 the grinding speed of the work pressed between the grinding and regulating wheels is produced by the relative motion of the two wheels. Whereas the grinding wheel is driven by a constant-speed motor, the revolutions of the regulating wheel can be progressively adjusted to the desired value within a speed range of 1 : 10 by means of a three-phase shunt commutator motor. Since, however, the regulating wheel is driven by the grinding wheel through the intermediary of the work-piece the shunt commutator motor operates as braking generator and delivers back to the three-phase supply system part of the power taken by the main motor. The regulating wheel is applied to the work and returned by hydraulic power. Notwithstanding the widely-differing driving units it was found possible, through ingenious design of the control gear, to coordinate their operation in such a manner that close error limits could be worked to and a high production achieved.

In the case of *planing machines* it is not simply a question of progressively varying the cutting speed within a range of about 1 : 10 and maintaining it constant immaterial of the load, but the table must also reverse rapidly at both ends of the stroke and run back as fast as possible to reduce the time wasted to a minimum, thus increasing production. The *rapid reversing drive with stabilizer* developed and patented by Brown Boveri completely meets this requirement, as proved by the oscillogram of a reversing cycle shown in Fig. 7. Notwithstanding the extremely short reversing times of approximately 0.5 second the table is reversed absolutely smoothly. The d.c. planing machine motor can be reversed some several thousand times per hour without detriment.

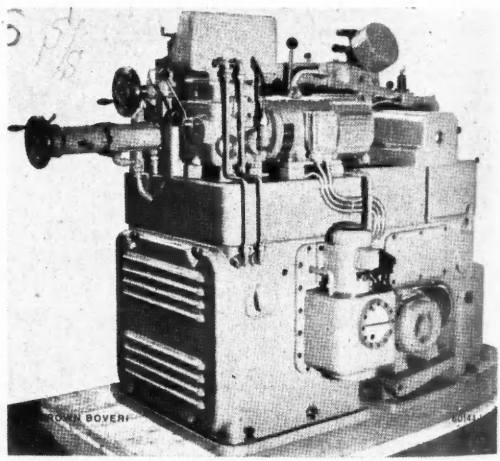
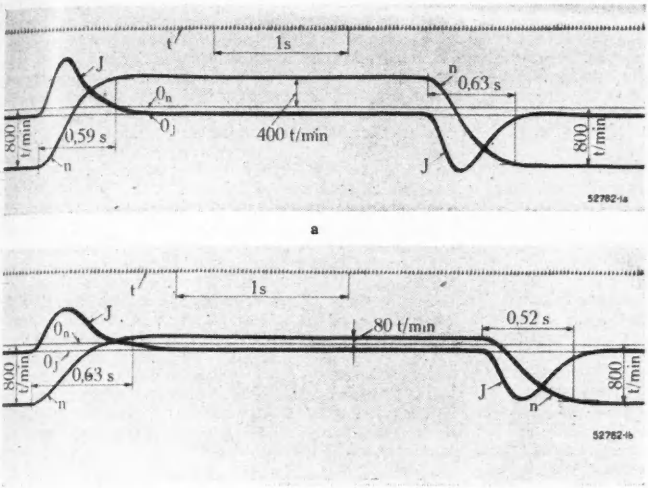


Fig. 6. **Centreless precision grinding machine with shunt commutator motor as variable-speed drive and braking generator (rear view).**

The shunt commutator motor serving for the adjustment of the grinding speed and as regenerative brake with drive from the counter-pressure wheel, will be seen in the centre.



The oscillograms show the reversal of the planer table at the two ends of the stroke. Reversing times are extremely short from lowest to highest cutting speed and maximum return speed.

n. Speed trace
(a) +800 to–400 to +800 r.p.m.
(b) +800 to– 80 to +800 r.p.m.

J. Main current trace

O_n. Zero line of speed

O_j. Zero line of curren

Timing wave.

Figs. 7a and 7b.
Reversing cycle of rapid reversing drive for a planing machine.

TAILLESS AEROPLANES AND FLYING WINGS.

By A. R. WEYL. (From *Aircraft Engineering*, December, 1944, pp. 340-352/360; January, 1945, pp. 8-14 February, 1945, pp. 41-46; March, 1945, pp. 73-81; April, 1945, pp. 103-111; May, 1945, pp. 133-145).*

INTRODUCTORY NOTE.

TAILLESS aeroplanes and flying wings form a category of uncommon aircraft in which designers of all countries display a special interest. The advantages offered by the suppression of a tail and the problems arising from isolated wing systems as aeroplanes are not obvious, and are rather involved. For many years, such aeroplanes have been a matter of controversy and of speculation; many attempts at solving the inherent problems were made. Yet, it is only in these days that there are indications that the tailless aeroplane will come into its own over the conventional aeroplane.

A study of the matter gives an excellent insight into the methods of engineering progress and the train of thought in modern aeronautics, and engineers outside aeronautical circles may find the following extract of general interest.

The ideal aeroplane can culminate in two different forms; the "Flying Wing" and the "Projectile."

The flying wing seems to be the ideal solution for large and economical transport aeroplanes and flying boats. This form of aeroplane is a logical consequence of the trend of development when a size is reached in which the wings offer sufficient space for the accommodation of the power plant, the fuel and the freight. In the case of passengers, a suitable minimum size is indicated by the requirements for their accommodation. At the speeds of modern air transport, surface friction is one of the main items for which propulsive power has to be expended, and as interference drag forms another item of air resistance, the flying wing is undoubtedly the most economical solution, since the interference drag can be reduced to zero and the friction drag to that minimum which is required for the generation of aerodynamical lift. Structurally, the distribution of the load along the span which is a necessity for the flying wing on the grounds of allocation of space, also results in a saving of weight, because of the reduction of bending moments and torsional stresses in the wing. The loads can be directly taken up by the lift forces. These favourable conditions permit the construction of flying wings in far larger sizes than conventional aeroplanes (where the loads are concentrated in a fuselage), at equal ratio of useful load to structural weight. This is another reason why tailless aeroplanes are of so much interest. The gas turbine which is smaller than an equivalent reciprocating engine, will greatly add to this interest, and when thermal jet propulsion (instead of airscrew drive) has come to stay in transport aviation, the distribution of the propulsive effort all along the span will mean a final diminution of local air loads and reactions on the wing structure.

The tail of an aeroplane is subjected to the wake from the wing, a downward-directed flow full of vorticity and eddies; to this is usually added the slip-stream caused by the propulsive devices. The aerodynamical forces exerted on the tail thus vary greatly in flight; this affects stability, trim and control of the conventional aeroplane. At large angles of incidence, or when high-lift devices are operating on the wing, the variations of the air flow at tail surfaces become so considerable that flying manœuvres (especially take-off and landing) are complicated for the pilot. Moreover, eddies shed from the wing are generally responsible for the occurrence of the phenomena of tailplane flutter and tail buffeting.

In the high-speed aeroplanes of the immediate future the effects of compressibility on the wings (which appear already at flying speeds now in use) will give much trouble to aeroplane tails. The stability is adversely affected by the phenomena of compressibility stall at the wing; very high control forces appear at the tail surfaces, and the shock waves formed at the wing give dangerous tail buffeting. This, at the present great speeds, is more experienced than ever before. It necessitates, among other precautions, to construct

*EDITOR'S NOTE.—In publishing this article we depart from our usual practise not to use abstracts from British Journals in the British Edition of *Engineers' Digest*. Our readers generally have access to these journals. In this instance we feel justified in making an exception because of the interest and extent of Mr. Weyl's articles, to whom we are especially grateful for preparing this abstract.

fuselage as well as tailgroup for far greater loads than the normal loads would impose. In view of these influences of high speed, the design of tails and fuselages becomes increasingly intricate. In addition to the weight, the tail offers a not inconsiderable contribution to the drag and also to the costs of production.

When thermal jet propulsion is considered, by means of a jet engine employing atmospheric air, or by self-contained rocket combustion, the presence of a tail is always found to be a serious disadvantage. It is not practical to subject any part of the tail to a thermal jet which, under service conditions, would impose on it concentrated aerodynamical loads, vibrations and swirl of hot gases. Thus jet engines and rockets must be arranged in such a manner that the tail always remains free from the jet. Even with twin jet engines, the designer is compelled to accept arrangements which are by themselves neither efficient nor convenient. The designer would be far less hampered in exploiting the possibilities offered by thermal jet propulsion, and the many advantages of completely submerged jet-engine installations could be more fully utilised on aircraft without a tail.

For smaller aeroplanes, the adoption of pusher airscrews is also impeded by the tail which causes either the choice of structurally unwelcome twin-fuselage arrangement, or equivalent inefficient structures to support the tail.

The tail is also a source of trouble for flying boats, since it requires protection against water spray and splash which also greatly reduces the seaworthiness of flying boats. In order to achieve, for the tail, the greatest possible protection from water loads, the freedom of design is greatly restricted. Moreover, the most economical " bat boat " shape cannot be employed when a tail is present. Heavier hull structures and hydrodynamically less efficient shapes are the consequence.

With respect to undercarriages, the presence of a long fuselage supporting a tail is distinctly disadvantageous. Since the aeroplane should assume a ground angle which is near to the stalling angle of the wing, the long fuselage often necessitates a higher undercarriage than the ground clearance would demand. This is not only structurally undesirable, but reflects adversely upon the safety, and deteriorates the field of vision of the pilot at a time when full vision is of vital importance. Moreover, tail wheels or protection buffers at the fuselage stern impose severe loads on the fuselage, and the advantages of tricycle undercarriages cannot be fully obtained when a tail is present.

With regard to housing and maintenance, the tailless aeroplane offers the advantage of being far shorter than a conventional aeroplane and in most cases the lower undercarriage would allow for a smaller overall height.

From the military point of view, the presence of a tail forms an obstruction for a rear defence in air combat. It also gives an attacker a welcome blind spot from which to attack without risk to himself. This lack of rear defence can be effectively overcome only by the provision of a gunner in the tail with an unobstructed field of fire and vision. This well tried expedient, however, has the disadvantage that a heavy weight is installed at the stern of the fuselage (increased moments of inertia of the aeroplane about the vertical and the lateral axis ; necessity of shifting engines, etc., forward, in order to retain the original position of the centre of gravity ; longer fuselage nose ; increased structural loads on the fuselage ; aerodynamically unfavourable shape of the fuselage stern, etc.) and renders the intercommunication between the members of the crew difficult. The spreading out of the crew over the fuselage is also disadvantageous for efficient armour protection and for centralised fire control. Moreover, even with good turret arrangements at the tail, the tail surfaces will still form welcome blind spots for an enemy aggressor, and thus additional gunners and gun positions are required (waist gunners and mid-under gunners). For these reasons, the tailless aeroplane is favoured by the military technician.

If one considers the problem of the " safety " aeroplane, i.e., of an aeroplane which may be safely handled without more than cursory training, the tail is apt to render the control complicated, and the danger of spinning arises. Tailless aeroplanes are less affected and can be rendered safe against spinning. They can have a high degree of inherent stability without becoming unmanœuvrable and uneconomical ; they can allow the execution of stalled glides while retaining full control during the stall. From abnormal attitudes, a tailless aeroplane may recover easier, and recovery from a stall is not subject to nose dives.

From these points of view, it is easily seen that the suppression of the tail gives quite definite advantages. It allows the aeroplane to be developed to far larger sizes. It frees the organs of stability and control from the wake of the wing and from the slipstream. It renders the approach to regions of compressibility easier, and it may even allow to pass the barrier which the velocity of sound sets up for the aeroplane. It facilitates the application of thermal jet propulsion and the adoption of pusher airscrews. It allows better solutions to problems for landing gear and for flying boats. It gives far greater scope to the designer of military aircraft and offers promising solutions for safety aeroplanes. It gives reduced overall dimensions, and makes production cheaper. For an equal expense of power, the tailless aeroplane would offer either higher speed or more useful load, in comparison with a conventional aeroplane. Being more compact, it also promises a better proportion between useful load and structural weight.

These reasons make it worth while to investigate the problems arising from the suppression of a tail.

For this purpose, a survey of past experience and achievements has been combined with a study of the main problems of tailless aeroplanes, viewed from the present stage of our knowledge. Though tailless aeroplanes still have certain deficiencies which require further research and experimentation along lines indicated, it can be safely assumed that, for specific purposes, the tailless aeroplane will form the most practical solution.

A SURVEY OF HISTORY AND PAST ACHIEVEMENTS.

Many trials have been made with tailless aeroplanes. Most of these were made unconnected with each other. They were based on the initiative of single experimenters and were greatly hampered by lack of understanding and by underestimating the problems involved. Among the earlier attempts, made before flying became a practical possibility, the following are worth while mentioning :—

Richard Harte of London, of whom only a patent dated 1870 has become known, invented the aileron-elevator controller at the wing tips, the trimming by way of shifting the centre of gravity, the constant-speed variable-pitch airscrew ; he also foresaw the necessity of a neutralization of the torque reaction of the airscrew.

Far more detailed was the project of a tailless twin-engined monoplane for which A. Pénaud and P. Gauchot obtained a patent in 1876. Pénaud is commonly known as the investigator of flight who emphasized the necessity of a tailplane for stability (1871), and his far-reaching tailless project has been generally overlooked. Pénaud had realised that "stable" aerofoil sections (i.e., those having reflexed camber) gave longitudinal stability to a wing system without necessitating a tailplane. His project shows many features which are commonly believed to be modern achievements, such as a cantilever wing with stressed skin construction (wood or metal), oppositely rotating airscrews of metal with

variable pitch and the possibility of feathering the blades in flight; retractable wheel undercarriage; a fuselage constructed as the hull of a flying boat; enclosed cockpit with an instrumental layout not unlike that of modern aeroplanes, including automatic-pilot devices. Pénaud seriously underestimated the power required.

Less advanced were the tailless aeroplanes developed by Cl. Ader between 1886 and 1897. They were practically constructed and experimented with and short flights are believed to have been made. They used steam engines and had gull-shaped wings. Many other investigators of the early days began their development with tailless aeroplanes, but were soon discouraged by the problems encountered and accepted the tailplane as a condition for human flight.

Nevertheless, the first free flight in Europe (Sept. 12th, 1906) has been performed by the tailless biplane constructed by the Dane, J. C. H. Hansen-Ellehammer. Instead of inherent stability, this aeroplane had an automatic longitudinal stabilising control, employing the weight of the pilot as a pendulum. Ellehammer left this principle with his subsequent aeroplanes and adopted a tailplane.

The subsequent success of the conventional aeroplane proved that human flight with engines was achieved. There was no necessity to probe further along new ways for a solution of the primary problem.

The next phase was the craving for stability. Many considered that an aeroplane in which the pilot had to devote his constant attention to the task of retaining an attitude of safe flight, and which required continuous control manœuvres, was not a practical proposition.

José Weiss, a French artist naturalized in Britain, was the first to achieve inherent stability by way of a stable wing necessitating no tailplane. He took this shape from soaring birds, which show great stability indeed when soaring with their tailfeathers tucked away. Weiss had no spectacular success, though his ideas were in many ways far advanced. He proved the stability of his wing, but his powered aeroplanes had to be equipped with tailplanes before they were practical to fly. Weiss gave much inspiration to the development of stability problems in England and contributed greatly to later achievements.

Aerodynamically, the wing shape preferred belongs to a category for which the name ZANONIA has become significant in view of a more intense development which took place in Austria and in Germany. ZANONIA MACROCARPA is a name of a Javanese plant which has a kidney-shape seed leaf which performs long and stable glides. German naturalists pointed out how useful a wing of this shape could be for a glider. This suggestion received the attention of Friedrich Ahlborn, an experimenter in aerodynamics who had become interested in stability. Ahlborn considered that the Zanonia seed-leaf form was an ideal solution to the stability problems involved in aviation, and tried long to encourage experimenters of flying to adopt such a shape for wings. In 1904, a reference to the qualities of the Zanonia raised the interest of two Austrians, Ignaz and Igo ETRICH. They soon achieved stable glides with a man-carrying glider. In 1906, their collaborator, F. Wels, succeeded in flying 250 yards from a hill. No controls were provided.

An engine and airscrews were subsequently fitted to this glider wing. The results of this combination were discouraging; after modifications and after separation from Wels, the Etrichs fitted a tail to their aeroplane. The outcome of this development was, in 1910, the "Taube" monoplane, of which hundreds were built. This type had unquestionable stability qualities, but suffered from poor manœuvrability and poor efficiency. Nevertheless, it showed that inherent stability can be a practical proposition.

Along similar lines but guided from observations of birds in flight, moved the work of the German physician, W. GEEST. His wing, however, was not shaped like the Zanonia; it had gull-shape with tilted-down wing tips similar to a soaring gull. Geest, too, adopted a tailplane. Several aeroplanes proved to have surprisingly good flying qualities even surpassing those of the "Taube."

To the most far-sighted experimenters belongs the Britisher, J. W. Dunne. He also was searching for inherent stability, realising in the aeroplane the ideal means for military reconnaissance. To a large extent, the modern development of the tailless aeroplane and of the flying wing is based on his work.

Dunne has been the first to introduce a stable wing system at which stability was achieved by a combination of sweep-back with wing twist. His work began in 1904. Secret experiments were made in Scotland later for the British War Office. A small number of experimental aeroplanes, mostly biplanes, were constructed. Though neither efficient nor very manœuvrable, these biplanes achieved remarkable successes. Dunne, an inexperienced pilot, was able to prove, in Dec. 1910, that an aeroplane could be flown completely uncontrolled along a given path of flight. A monoplane constructed in 1911 incorporated diffuser wing-tips and had, generally, all features which are to-day characteristic for tailless aeroplanes. Dunne retired for reasons of bad health. In 1915, the American firm of BURGESS acquired the licence, and a number of Dunne biplanes were built and flown in America up to 1917.

A new line of development was opened by the Frenchman ARNOUX, a gifted experimenter whose work has been overlooked as well as ridiculed. From 1909 to 1923, he worked on the problem of making a plain wing stable by the use of aerofoil sections with an upwards reflexed rear part. In 1940, he lost his life fighting for his country as a fighter pilot.

Arnoux was interested in the tailless principle as such for the development of the pure flying wing and not in inherent stability. He believed that a tail and similar exterior control surfaces were attachments which could be dispensed with. In 1909, he constructed a tailless biplane consisting of two plain superposed wings which could be warped. This and the airscrew thrust were considered sufficient for control. A monoplane along the same lines followed, and in 1913 he exhibited a tailless low-wing monoplane with pusher airscrew, consisting of a plain rectangular wing, the trailing edge of which was formed by two full-span controllers which, even in their downwards deflection, still formed a reflexed tail portion of the aerofoil section. Arnoux was thus the creator of the "Flying-Plank" category.

In 1919/20, a biplane was constructed along the same lines which gave satisfaction in flight. Two years later, a racing monoplane with 320 h.p. designed for the Coupe-Deutsch Race, which gave practically no field of vision to the pilot, was damaged during trials. Having achieved the simplest form of an aeroplane, Arnoux deserves great merit in aeronautical engineering.

At the time when Arnoux had his unfortunate experience, another novel form of tailless aeroplanes was being tried in the form of a racing monoplane. This was based on the stability of an "inverted-arrow shape" (i.e., sweep-forward of the wings). This was designed by Landwerlin and Berreur and had a 700 h.p. engine. As in Arnoux case, the experiment was too daring. The aeroplane was not only unfinished in time for the race but was quickly discarded.

Quite a different approach to the tailless aeroplane came from the conception of "dynamic" soaring flight, i.e., soaring based on the utilisation of gusts. It was assumed that the wing, for this purpose, had to undergo quick changes of incidence, and obviously, in this case a tail forms a direct impediment to do so.

In 1920, Wenk and Peschkes built a tailless

monoplane, the "WELTENSEGLER" (Worlds Soarer), consisting of a rectangular wing with dihedral, to the tips of which long swept-back parts were fitted under anhedral and with smaller incidence than the main wing. The wing thus formed in its front view, an M-shape. The first real soaring flight of 2 min., cruising above the point of take-off, was performed with a sailplane of this kind. However, accidents due to weaknesses in the wing structure occurred and the rather interesting design went into oblivion. A somewhat similar design was a sailplane of V. Parseval and students of the Berlin Technical University. This was successfully flown, but was not considered superior to contemporary sailplanes.

Far more important was the painstaking development work of A. Lippisch whose name has been closely connected with German sailplane and glider construction. After early experiments with primitive tailless gliders, Lippisch developed the STORK type which had a wing with pronounced sweep-back and wash-out like Dunne, but with more modern aerofoil sections and a suitable change of sections along the span, and demonstrated this type not only as a glider but as a light aeroplane. During this development, in 1930, he created the DELTA category. The straight trailing edge of this triangular wing plan was employed to house several pairs of controllers. Lippisch had also found it practical to divide the control functions among different control surfaces. The DELTA type, too, was developed in successive experimental aeroplanes up to 1939, forming probably the closest approach to practical aeroplanes reached with tailless aeroplanes to that time. Lippisch's final idea was the large flying wing. Towards the end of the war, he seems to have designed the tailless Me. 163 rocket interceptor and a less known tailless jet-propelled fighter.

Lippisch approached the matter with the full scientific equipment of the modern aeronautical engineer. His studies of the subject have done much to prepare the way for the more recent development.

In Russia, Tscheranowsky experimented with his "Parabola" flying-wing sailplanes and light aeroplanes. Of French attempts by Abrial and Auger, Nieuport-Delage and others, Fauvel's work deserves mention. Based on the flying-plank principle of Arnoux, he achieved, in 1936, the first tailless aeroplane which not only was granted a certificate of airworthiness by the French, but with which an altitude record could be established.

J. K. Northrop in U.S.A. in 1939, constructed an experimental twin-engined flying-wing of very progressed appearance with which intensive flying tests were made. More recently, Northrop has constructed a tailless single-seater fighter on the basis of his experience.

The work of the brothers Horten in Germany during 1934/43 with tailless sailplanes, tailless motor-gliders, etc., is more or less an amplification of the research of Lippisch. Their flying-wing sailplanes, however, have proved that, in this class, the tailless sailplane can be at least equivalent to the best conventional sailplanes hitherto built.

A particular side-line of the tailless aeroplanes comprises such which have wings of very low aspect ratio, especially those with wings of approximately circular shape. The omission of a tailplane is here a necessity, as the plan shape gives the possibility of stalled glides and landings at very high angles of incidence, due to the particular airflow over the wings. In about 1932, the peculiarities of such wing systems were realised in the U.S.A. There and in Italy corresponding "fool-proof" aeroplanes were being constructed. They remained, however, without success, after having raised great expectations.

Another side-line is the annular wing system which also promises outstanding qualities in stability and in performance. Attempts have been made in this direction in Germany and in England where the Cedric Lee type of Tighman Richards achieved quite a success. Even in modern times, this kind of tailless aeroplane is occasionally suggested for good engineering reasons.

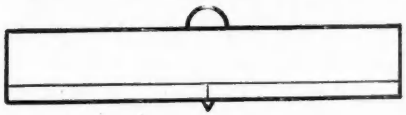
CLASSIFICATION.

Tailless aeroplanes are self-contained flying wing systems. There are two ways of rendering such wing-systems capable for sustained flight in the same manner as the conventional aeroplane, i.e., comprising a lift-producing wing plus a stabilising tail. One way is to provide the wing of a conventional aeroplane, i.e., a purely lift-producing wing, with an apparatus giving *automatic* control for stability, such as the modern "Automatic Pilot." Ellehammer (1906) tried to solve the problem that way. No further attempts have been made since and one may safely assume that, for various reasons, this way of arriving at a tailless plane is not practicable.

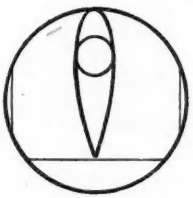
The other way is to adapt a purely lift-producing wing (aero-foil) so that it obtains the same degree of inherent stability which the conventional aeroplane possesses by virtue of its tail. Such an adaption can comprise: the choice of aerofoil sections; the plan shape of the wing; the addition of stabilising wing tips; and/or the combination of all such means. This second way is the method generally employed in the design of tailless aeroplanes.

Classification of tailless aeroplanes belonging to this general group is best done in respect to the plan shape. Thus the following classes may be distinguished:—

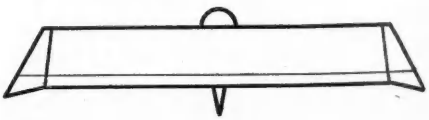
(1) The FLYING PLANK, a plain wing without any sweep, with or without taper, completely relying on the stability qualities of the aerofoil section. Structurally, this is the ideal type, and basic development will hence always try to approach this ideal as far as possible.



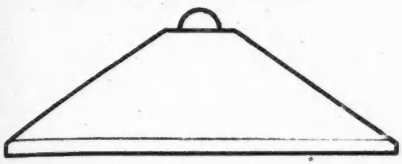
(2) DISK class, having a wing of circular, parabolic or rhomboidal plan, of an aspect ratio of less than 4. This class comprises the low-aspect wings for which the conditions of stability and controllability differ from those of the Flying Plank class.



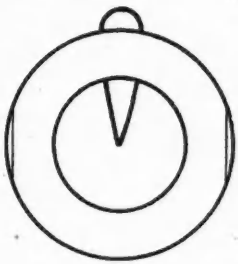
(3) DIFFUSER-TIP Class.—The conception of this class is that of a plain aerofoil of purely lift-producing qualities to the ends of which stabilising "frills" are fitted.



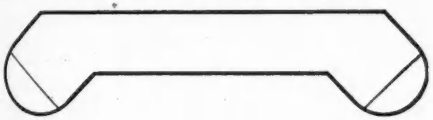
(4) DELTA Class.—A wing of triangular or trapezoidal shape which has over the major part of its span a swept-back leading edge and a more or less straight trailing edge.
This class may be conceived as a combination of the Flying Plank and the Arrow.



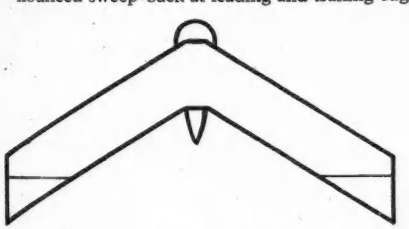
(5) ANNULAR Class.—Wing plan of annular ring shape. The outer contour may form a true circle or a rhomboid.



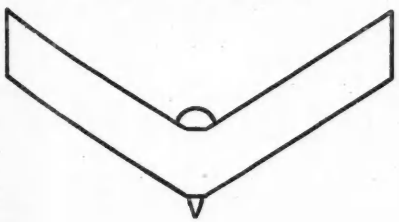
(6) ZANONIA Class.—Principally a relation of the Diffuser-Tip class, but usually having a wing of crescent, kidney or maple-seed plan shape with tips of pronounced negative incidence ending in backwards extended and upturned parts.



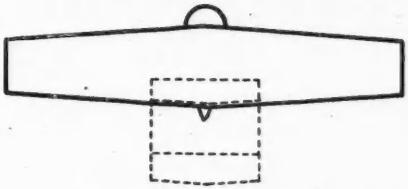
(7) ARROW Class.—Arrow-shaped plan with pronounced sweep-back at leading and trailing edges.



(8) BUZZARD or INVERTED-ARROW Class.—Plan shape with a pronounced sweep-forward (i.e., tips forward of the centre of the wing).



(9) MIXED ARROW-BUZZARD Class.—One possibility is to have sweep-forward in the inner and sweep-back in the outer wing parts (a shape which soaring birds often assume). A. King has projected a very interesting tailless aeroplane of this kind.
The other possibility is to have sweep-back inboards and sweep-forwards in the outer parts of the wings. This has not yet been utilised.



A special class is formed by tailless aeroplanes which for certain manœuvres, such as take-off and landing, can extend a tailplane from the wing in a similar way as in modern aeroplanes which extend landing flaps (as high-lift devices) from the trailing edge of their wings.

Sections of this class of "temporary tailless" are possible, namely those extending a tailplane from the trailing edge of the wing for stabilisation or for the balance of moments, and those which extend a tail-first stabiliser from the leading edge of the wing. Both have not yet been practically attempted, but offer definite advantages for the solution of intricate trim problems of stable wing systems.

In general, a stable system incorporates the functions of a stabilising balancing tailplane in its wing. Thus the classes based on the effect of sweep-back are related to the conventional aeroplane having a tail, while the sweep-forward classes are related to the tail-first aeroplane. The Flying-Plank is aerodynamically related to the principle of the tandem aeroplane.

The plan shape of the wing has a great influence upon the distribution of the lift over the wing span, and this again affects not only the performance but the lateral stability. Sweep-back gives (even without wash-out) the greater lift in the centre; the Flying Plank will generally have a lift distribution which approaches a half-ellipse shape, and sweep-forward will give the greater lift at or near to the wing tips.

THE PROBLEM OF LONGITUDINAL STABILITY.

In general, this problem is overestimated as being the key to the whole question of achieving a practical tailless aeroplane. It is, however, so that there is no major difficulty to secure static longitudinal stability, i.e., the tendency to return to a state of equilibrium after experiencing a disturbance from it. The means for laying out a wing system which is statically stable in motion about its lateral axis, are well understood.

Aerofoils exhibit a travel of their centre of pressure, i.e., the resultant aerodynamical force produced by the wind intersects the chord of the wing at different points, according to the angle of incidence the aerofoil chord makes with the direction of the wind. If this travel of the centre of pressure is so, that with an increase of the angle of incidence, a position is assumed which is more forward (i.e., towards the leading edge), the aeroplane will become "tail-heavy," i.e., the wing will try to increase the incidence still further. Such a travel of the centre of pressure is unstable, since any disturbance (by a gust, for instance) will pitch the aeroplane away from its original state of equilibrium (i.e., from its incidence of normal flight).

If, otherwise, the travel of the centre of pressure is so, that when the incidence increases, the resultant

aerodynamical force moves towards the trailing edge of the wing, the wing possesses static longitudinal stability, since the resulting nose-heaviness (the centre of gravity being assumed to remain in a fixed position) will produce a tendency to decrease the angle of incidence again.

For a plain aerofoil (Flying Plank), the travel of the centre of pressure is a matter of the aerofoil section. A flat-plate aerofoil or, corresponding with this, a symmetrical aerofoil section, has in this regard, stability or, ar least, indifferent stability, while simply cambered aerofoils such as those most frequently employed with conventional aeroplanes, show section instability which is the greater the more expressed the camber of the mean camber line of the aerofoil section. In their upside down position, i.e., with their convex side of the camber facing the ground, such simply cambered sections would, however, be stable.

When at cambered aerofoil sections, the trailing edge is tilted up against the curvature of the front part (reflexed camber), it is possible to decrease the section instability due to the camber of the front position; by further reflexing, it is even possible to obtain indifferent or positively stable aerofoil sections.

The consideration of longitudinal stability is greatly helped by the conception of the "aerodynamic centre." Hydrodynamic theory of potential flow establishes that, for any aerofoil section, there is a point ("focal point") about which the moment of the lift force becomes independent of the angle of incidence, and that this point is situated at quarter-chord distance behind the leading edge of the aerofoil. At aerofoils in a real fluid, i.e., the air, the experiment shows that, over the essential range of the incidences, which is required for flying, the moment of the lift is, with very good approximation, linearly proportional to the angle of incidence thus, that there is an aerodynamic centre in analogy with the "focal point" of the theory, and that, further, this aerodynamic centre is near to the quarter-chord point.

Using the conception of the aerodynamic centre, the criterion for static longitudinal stability becomes very simple indeed. It stipulates only that stability exists when the centre of gravity of the aeroplane is located in front of the aerodynamic centre; if both coincide, the stability is neutral, and when the centre of gravity is behind the aerodynamic centre, there is instability. Stability cannot be considered without a state of equilibrium. With simply cambered aerofoil sections, equilibrium cannot be established when the centre of gravity is so located as static longitudinal stability would demand. Hence it is obvious that such aerofoil sections are unsuited for the Flying-Plank class, since when stability shall exist, a tailplane is required to balance the nose-heavy pitching moment caused by the stable location of the centre of gravity. With symmetrical aerofoil sections, only neutral stability can be achieved with a plain aerofoil, though by placing the centre of gravity low below the aerodynamic centre, a certain amount of static "pendulum" stability can be secured in this case. Heavily reflexed aerofoil sections, however, are in a position to give static stability as well by the location of the c.g. in front of the aerodynamic centre, as equilibrium in that position. Such aerofoil sections are indeed a necessary condition for every tailless aeroplane of the Flying-Plank category, i.e., for wing systems which rely entirely on section stability.

Reflexed aerofoil sections of that stable nature have not yet been extensively investigated, though with conventional aeroplanes, sections with lightly reflexed camber lines are being used more and more because of their aerodynamical advantages. Heavily reflexed camber sections suffer from low maximum-lift, but there are indications that, otherwise, they need not necessarily be considered inferior.

Opposite to section stability is the stability by means of the shape of the wing. Here a general law is valid for the longitudinal stability of every form of aeroplane. This says that stability can exist only if components of the aeroplanes or parts of the wing in front have greater lift than components of the aeroplanes or parts of the wing behind them. Consequently, for a stable wing system relying on shape stability, those parts of the wings which are leading, must generate the greater lift per unit area than those behind.

It is obvious that, for stability, sweep-forward (Buzzard category) must be combined with wash-in (i.e., incidence increasing towards the tips), or with aerofoils of larger camber towards the tips, while the Arrow category with its sweep-back must have wash-out at the wing tip or an equivalent change in wing sections towards the tips.

Such stability of shape is, of course, not bound to stable aerofoil sections. But both factors, section stability and plan-shape stability may be combined, and the majority of all modern tailless aeroplanes is indeed a combination of both factors. The Delta category is a typical example for this. Its relatively small effective sweep-back would not give stability with unstable aerofoil sections, but is sufficient to give perfect stability with sections having neutral section stability, as, for instance, symmetrical sections.

The stability of the complete aeroplane can differ from that of its stable wing system when excrescences such as nacelles, fairings for engines, external controls or other components are added to the wing. At streamline shapes, the aerodynamic centre is liable to shift at very small angles of incidence; this refers also to thick aerofoil sections. Instead of remaining stationary, the aerodynamic centre travels forward at very small deflections from the angle of zero effective incidence; this is well known from airships. The result, for the tailless aeroplane is that within such small angles of incidence (as for instance in dives or at high speed) instability may exist throughout while at all other angles of incidence (cruising speed and climb, for instance), the aeroplane is perfectly stable. The better the streamlining, the more this instability phenomenon is likely to exist.

With regard to section stability, the action of controllers forming the trailing edge of the wing may affect this stability adversely when the controller is depressed, since this nullifies the reflex in the camber. Such controllers must have limited motion for reasons of stability. Similarly, controllers at the wing tips may adversely affect the stability by eliminating the wash-out or wash-in. Controllability and stability are hence interconnected in the tailless aeroplane.

A more serious problem is formed by the dynamic longitudinal stability. This can only be considered at a statically stable aeroplane and refers to the manner in which the aeroplane tries to return to its original equilibrium after a disturbance. The return motion is that of an oscillation about the lateral axis and, for dynamical stability, it should be damped. Aeroplanes react to disturbances in pitch by a motion which can be approximated as a superposition of a short period oscillation which is mainly connected with the incidence, and a long-period oscillation which is mainly due to variations of the flying speed.

While, however, conventional aeroplanes never suffer from lack of damping in the short-period oscillation, the tailless aeroplane is insufficient in aerodynamical damping in pitch (due to the absence of the damping tailplane) and thus may easily exhibit lack of stability when the moment of inertia about the lateral axis is large (due to large sweep-back, or heavy control parts near the wing tips, for instance). When there is not sufficient dynamic stability, i.e., that quick oscillations in pitch may persist, non-steady lift and/or the Katzmayr effect may seriously influence the wing structure

(flutter) and the path of flight. With the phugoid oscillation, certain difficulties may be expected with high-performance flying wings.

In general, however, the problem of longitudinal stability, though needing closer investigation, do not seem of a nature which would require the surmounting of great obstacles. The past flying experience collected confirms this view.

PROBLEMS OF LATERAL STABILITY.

The problems of lateral stability seem far more involved. From flying experience, it can also be deduced that satisfactory solutions are far more difficult to achieve in this direction.

Lateral stability concerns the motion about the longitudinal axis (roll) and the motion about the normal axis (yaw); both motions are interconnected. Static stability in roll is expressed by the derivative of the rolling moment in respect to the angle of side-slip, static stability in yaw by the yawing moment in respect to the angle of side-slip. For the ability to fly in circles without variation of the flying speed (steady turns), the damping due to the angular velocity of yaw is decisive.

It is critical for the tailless aeroplane to achieve appropriate weathercock stability (yawing moment due to side-slip) for the whole range of incidences and side-slip angles. Here again the tendency of streamline bodies such as nacelles to increase an initial deflection from zero side-slip (i.e., the tendency to adjust itself across the airflow) is especially troublesome, since fins have no such great lever than with conventional aeroplanes. The usual remedy is to fit fins to the tips of swept-back wing systems, but experience indicates that this is a remedy full of disadvantages of aerodynamical and structural nature. Moreover, the stabilising moment required for the weathercock stability is not proportional to the effect of fins at such tailless craft which have large and well shaped nacelles and fairings in front of the leading edge. In this respect, the flying wing offers a complete remedy.

The dynamic lateral stability is greatly influenced by the weathercock stability. If this becomes excessive, spiral instability may occur. With the average tailless aeroplane, this is less likely to occur, though the tailless plane will generally suffer from lack of proportionality between the weathercock stability and the damping in yaw for the reasons indicated. This may become critical at high speed or in a dive, while at large angles of incidence (climb) there may be an inability to fly steady turns, due to excessive damping in yaw.

The use of conventional ailerons giving adverse yawing moments will affect the tailless aeroplane more unfavourably than the conventional aeroplane. Improved control devices hence become imperative.

In general, it may be concluded that small tailless aeroplanes, especially those with tractor airscrews, will be subject to certain imperfections in their flying qualities due to deficiencies in lateral stability. This could be greatly improved by control and stability devices which, though known for many years, are not yet sufficiently experimentally explored and investigated in full-scale research. Thus, for the present, the small tailless aeroplane may also require a different technique in flying due to its imperfections.

Conditions seem far more favourable for large Flying Wings. But even here new control and stability devices would be of great help, aerodynamically and structurally.

With the Flying-Plank category and with types relying on an effective sweep-back, dihedral has been found disadvantageous. It might be helpful for the Buzzard category. Vertical fin surfaces are, in general, not desirable for tailless aeroplanes, but in most cases, they cannot be totally avoided. For the take-off, a central fin, possibly located in the slip-stream, is required for direction during the transition phase. Fin surfaces at the wing tip have the advantage that they act at the greatest possible leverage, and that the resultant aerodynamical force at them forms the stabilising moment for the weathercock stability. For the damping in yaw, however, they seem inferior to central fins. The "toed-in" design of such wing-tip fins (or their respective cambering) is of great help for the stabilising effect. This is true for every category of tailless. Superior to all sorts of vertical fin area seem " frilled " wing tips, especially the diffuser tip.

Tailless aeroplanes can be made to spin, but usually they are neither easily brought into a spinning motion nor is it difficult to recover from it. This is understandable if it is realised that the tail of a conventional aeroplane is greatly responsible for bad spinning qualities. Thus the tailless aeroplane can be safer for the execution of stalled glides and is more suited to safety aeroplanes which less skilled pilots can be entrusted to handle. Tailless aeroplanes can easily be fitted with devices which exclude auto-rotation and which thus allow them to fly stalled without danger to spin. Moreover, flying experience with lightly loaded tailless aeroplanes of Hill and Lippisch indicates that the transition from a stall to normal flight can be effected without an intermediate dive to gain speed; this is quite contrary to the behaviour of conventional aeroplanes and can be considered as a great factor of safety. Tailless aeroplanes which shall not be flown in aerobatic manœuvres, lend themselves well to the adoption of two-control operation, but this implies the introduction of better rolling-control devices.

CONTROL SYSTEMS FOR TAILLESS AEROPLANES.

Great progress with tailless aeroplanes can be expected from the introduction of improved control systems. Trim might be effected by shifting the centre of gravity within the limits permitted by longitudinal stability, while the variation of the angle of sweep-back for the same purpose seems unpractical. For the control in yaw, brake devices have been introduced instead of vertical rudder surfaces. Such brake-rudder may be formed by spreading flaps in the trailing edge or by spoiler flaps nearer to the leading edge of the wing. Lift-spoilers suffer greatly from lag and are, hence, unsuitable for control purposes. This is also valid for the rolling control by the means of lift-spoilers (interceptors), though such lift-spoilers in combination with normal ailerons offer certain possibilities.

The slot-lip aileron has disappointed due to its sluggish action, but there are indications that it might be improved, though it will always cause a loss of flying performance which makes it acceptable only for safety aeroplanes. Retractable ailerons of the lift-spoiler type offer also certain prospects but require more research and development before their value can be assessed for tailless aeroplanes.

Flap-like controllers influence the stability greatly, but Lippisch has adopted an arrangement overcoming this disadvantage though causing other inconveniences. As elevators, it would be desirable to have direct acting controls giving lift for climb and down-lift for descent (as with the tail-first aeroplane). Such arrangements are possible with tailless aeroplanes, but are not considered practical, as far as present experience goes.

Floating controllers forming the wing tips formed the essential feature of the earlier Pterodactyl's of Hill. To-day they are no more considered an advantage for tailless aeroplanes, though floating aerofoils in front of the leading edge of the wings seem to have been adopted with success for the purpose of supplying trimming moments when high-lift landing flaps are operated.

HIGH SPEED STEAM ENGINE WITHOUT LUBRICATION.

By H. FRANK and J. RAIS. (From *VDI Zeitschrift*, Vol. 89, Nos. 5/6, February 3rd, 1945, pp. 64-66).

A STEAM engine to operate without cylinder lubrication has been designed and built by the Skoda Works for a special purpose, where oil-free exhaust steam and highest economy at even partial loads are vital requirements. The engine was built for an output of 440 h.p., with live steam of 43 kg. per sq. cm. pressure and 380 deg. C. temperature, the back pressure being 7-9 kg. per sq. cm.

Aiming to secure oil-free exhaust from a reciprocator, the Skoda Works had carried out extensive experiments with regard to the use of carbon seals. However, these experiments, conducted since 1935, had been confined to considerably lower pressures. Thus, when faced with the present task, a new approach to the problem had to be made. The new series of tests were concerned with finding the most suitable type of carbon material, most suitable, that is, with regard to mechanical strength, thermal expansion, wear, and ability to withstand high operating temperatures. The most suitable material for the piston and the piston rod had also to be ascertained. Furthermore, an existing engine was equipped with carbon seals in order to measure leakage and other data. Carbon is adversely affected by the presence of oil, a sticky mass being formed which exerts an abrasive action upon the piston rings and wears them down with great rapidity. Particular attention had therefore to be paid to preventing lubricating oil from the crank case, from reaching the carbon seals. In this respect the provision of duplex scraper rings with interdrainage proved most helpful. These rings are now made of sintered iron in place of bronze, as hitherto used.

Carbon is a very good material for sealing purposes and by no means inferior to a metallic seal provided the rubbing parts to be sealed are as hard as possible and have a mirror-type surface finish. Should this not be the case, carbon particles will lodge in any existing pores and wear of the carbon rings will be inevitable.

A horizontal engine design had to be ruled out for reasons of cost, and a vertical design had therefore to be resorted to. A multi-cylinder design had to be chosen, since large size carbon seals are not feasible because of danger of breakage. It was, moreover, necessary to decide upon a single-acting engine type in order to eliminate the stuffing boxes. The specified engine output called for a six cylinder design with a bore of 190 mm. and a stroke of 200 mm., the engine speed being 750 r.p.m. This results in a mean piston speed of 5 m. per second, which is a high value hitherto rarely used in steam reciprocator practice.

Upon removal of the cylinder head, the carbon rings (a), as shown in Fig. 1, are slipped over the piston (d) together with the ring carriers (b). Circular leaf springs (e) serve to press the carbon rings lightly against the wall (f) of the cylinder. The piston crown is connected with the piston rod by means of the bolts (h). As these bolts exhibited fissures after short time in service, they were subsequently replaced by longer ones. The method employed for sealing the valve spindles is outlined in Fig. 2. Here it will be seen that the carbon bush (b) serves both as guide for the spindle (a) and as first stage gland, the steam pressure being throttled to a certain extent by the labyrinth-action of the grooves provided in the carbon bush. Sealing of this carbon bush against the valve body is effected at top and bottom of the bush by means of the elastic copper packings (c), the required degree of compression being exerted by the threaded gland (d).

The stuffing box proper is constituted by the ring carriers (e) containing the carbon rings (f). Each of the latter is composed of three circular segments, the segments of adjacent rings being staggered by 60 deg.

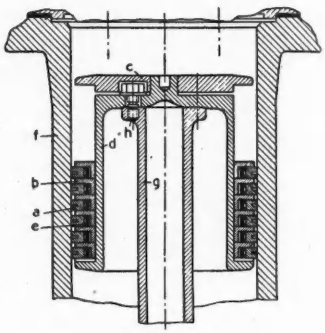


Fig. 1. Carbon seal of piston.
(a) carbon rings (b) ring carrier (c) piston crown (d) piston (e) circular leaf spring (f) cylinder (g) piston rod (h) bolt.

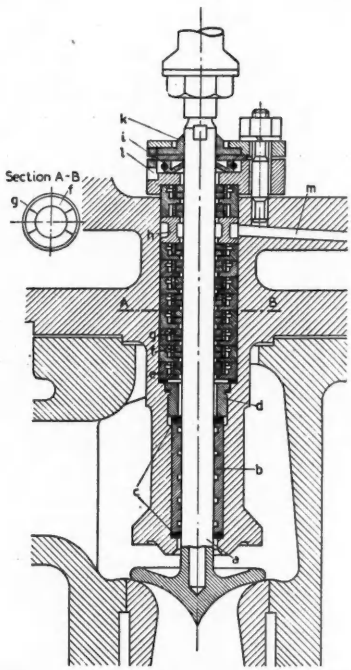


Fig. 2. Stuffing box of admission valve spindle with carbon rings.
(a) valve spindle (b) carbon bush (c) elastic packings (d) tightening nut (e) ring carriers (f) carbon rings (in 3 segments), with mutually staggered joints (g) leaf springs (h) annular distance piece (i) oil scraper (k) oil scraper with scraper edge (l) oil drain (m) connection to lock pressure line.

(Detailed section A-B in Fig. 2). The carbon segments are pressed against the valve spindle by means of the circular leaf springs (g). Furthermore, locating pins are provided to keep the carbon segments from rotating. In order to prevent the leakage of steam to atmosphere, a distance piece (h) is inserted below the two topmost rings, this annular distance piece connecting with the back pressure steam space by means of the duct (m). The two topmost carbon rings therefore act only as seals against the back pressure of the engine. In this way steam loss is kept to a minimum.

The rings (i) and (k) act as oil wipers, with the leakage oil being led away through the opening (l).

The mutual angular disposition of the six cranks of the engine crank shaft is indicated in Fig. 3. The connecting rods are forged and milled in order to keep their weight to a minimum. The big end bearings are made in cast steel halves, while the crosshead bearings are of the box type. The light metal crossheads have wrist pins of special bronze. The crank case is a single welded piece in order to avoid bolting the crank shaft bearings; the latter are bolted to pedestals enabling the withdrawal of the crankshaft to one side without lifting it. The cylindrical crosshead guides are made in halves and can be easily removed together with the crossheads through the openings provided in the engine casing. In the original engine the piston rods and certain other parts were made of stainless steel, but this precaution was later found to be unnecessary.

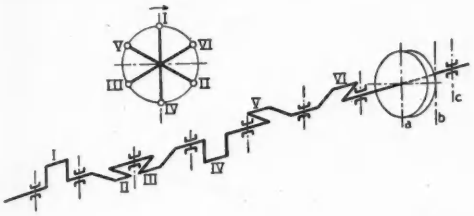


Fig. 3. **Crank shaft diagram.**
(a) flywheel (b) generator (c) bearings.

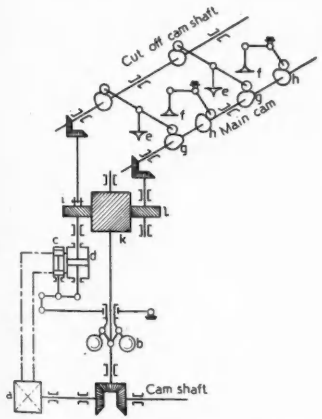


Fig. 4. **Valve control mechanism.**
(a) pump for governor oil (b) governor (c) pilot valve (d) slave cylinder (e) admission valves (f) exhaust valves (g) (h) cams for admission and exhaust valves respectively (i) movable gear (k) driving gear (l) non-movable gear.

The employment of a mechanical governor had to be ruled out because of the high engine speed and the large controlling forces required, and a pressure oil governor system was therefore adopted, as shown in Fig. 4. The pressure oil pump as well as the gear type lubricating oil pump are driven from the engine shaft.

Referring to Fig. 4 it will be seen that the small fly-ball governor (b) acts upon the pilot valve (c) of the slave cylinder (d). Valve control is effected in a novel manner, there being a cut-off control lay-shaft in addition to the main lay-shaft. The admission valves (e) are controlled by the cams (g) and the exhaust valves by the cams (h). The main lay-shaft revolves at constant speed, while the angular position of the cut-off lay-shaft relative to the main lay-shaft can be adjusted by shifting the pinion (i) by the movement of the piston of slave cylinder (c). Electrical remote engine speed control is provided. The engine is equipped with lubricating oil and pressure oil coolers, oil filters, and an emergency governor with oil hydraulic operation of the throttle valve. A manually operated pressure oil pump to set up the required oil pressure for starting is also provided. Provision for the absorption of thermal expansion is made at all vital points, including the steam piping.

The steam supply line from the boiler was laid out with a minimum of bends, a distributing header being provided close to the cylinders. From observations made at points of the live steam connections close to the admission valves, it was found that there prevailed a weak steam oscillation of a frequency corresponding to the rotational speed of the engine. In addition to this, higher harmonics and a certain amount of non-harmonics were also found to prevail. The most suitable means for the suppression of these oscillations has not been found as yet. As the compression amounts to about two-thirds of the admission pressure, there also occurred a small amount of vibration of the admission valves, but this could be eliminated by changing the valve springs.

Compared to a slow speed poppet-valve engine of equal power at 125 r.p.m., the present engine affords a saving in weight of some 60 per cent. At the end of August, 1944, the engine had been in service for about 8,000 hours without showing any marked wear of the carbon rings. The amount of cylinder lubricating oil saved during this period amounts to more than 5,000 kg. The guaranteed spec. steam consumption was 11.2 kg. per kW. hr. with a tolerance of +5 per cent, with a load of 410 h.p. This compares with a measured consumption of 11.95 kg. per kW. hr., that is, +6.7 per cent in excess of the guaranteed consumption. From diagrams taken at a later date, it was, however, found that two cylinders showed insufficient compression owing to faulty adjustment of the valve control. It is therefore confidently expected that after proper adjustment has been made the guaranteed steam rate will be met without tolerance. The indicator diagrams reproduced in Figs. 5 and 6 were taken with an electrical indicator. They clearly show the resonant oscillations occurring during the admission period.

Fig. 5. **Pressure vs stroke diagram.**

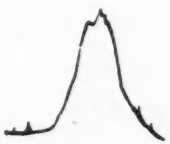


Fig. 6. **Pressure vs time diagram.**

THE SPECIFIC RESISTANCE OF CERAMIC INSULATORS AT HIGH TEMPERATURES.

By E. F. RICHTER and W. WEICKER. (From *Electrotechnische Zeitschrift*, Nos. 7/8, February 25th, 1943, pp. 103-104).

THIS article describes a new method developed by the "Physikalisch-Technische Reichsanstalt" for measuring the specific electric resistance of ceramics used in the manufacture of insulators.

METHOD OF MEASUREMENT.

The samples used are circular discs of 5 mm. thickness (Fig. 1). To ensure a clearly defined capacity, as required for measuring dielectric constants, the measuring electrodes have the form of a shield ring condenser and are baked on to the surfaces of the discs. The use of platinum electrodes is recommended, as silver is not suitable for measurements on materials containing magnesium silicates, if the temperature exceeds 450 deg. C.

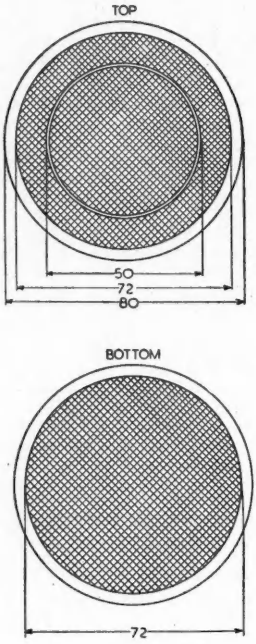


Fig. 1. Sample piece. Dimensions in mm.

It is necessary to ensure that the temperature of the thermo-couple is exactly the same as the temperature inside the sample. This is made possible by preventing heat leakage through the electric cable connected to the thermo-couple and by increasing and decreasing the temperature slowly. Furthermore, the on-load current of the furnace must not be allowed to influence the measuring circuit.

It was noticed that, if certain materials were subjected to higher temperatures, the current passing through them was accompanied by a flow of matter, which means that ion-conductivity plays a part in the conductivity at these higher temperatures. If, in such cases, a D.C. pressure is applied, the intensity of the current passing through the insulator decreases slowly, due to an electrolytic "cleansing effect."

This behaviour of certain ceramics makes it necessary to abolish the old method of measuring, whereby A.C. was used for making measurements at high temperatures and D.C. for lower temperatures. At present two methods are used, one for high temperatures and one for low. In both cases A.C. pressures are applied. In the high temperature range (tan $\delta \gg 1$) where the specific resistances are of the order of 10^8 to 10^9 Ω cm., A.C. of 50 cycles per second is used. The impedance is calculated from pressure and current measurements; the wattless component of the current, with regard to the total current indicated on the instrument pointer, can be neglected. In the low temperature range (tan $\delta < 0.1$) the loss factor tan δ and the dielectric constant ϵ of the material are measured on the Schering bridge, and the specific resistance ρ [Ω cm.] is calculated from the following formula, f being the frequency of the A.C. potential applied.

$$\rho = \frac{1.8}{f \,.\, \epsilon \,.\, \tan\delta \,.\, 10^{-12}} \quad .. \quad .. \quad .. \quad (1)$$

This formula is valid under the assumption that the equivalent network of a condenser with dielectric losses, is a loss-free condenser with an ohmic resistance connected in parallel, an assumption which has been proved to be correct for a great number of ceramics. It has been found that in the gap between the two groups of measurements, the curve representing the ohmic resistance, as a function of the temperature, gradually merges into the curve representing the impedance. Measurements made under a pressure of 100 volts are sufficiently accurate: the increase in the temperature of the sample, due to the measuring current (switched on for 1 minute intervals) remains within allowable limits, even at high temperatures. Identical results are obtained whether the measurements are carried out at increasing, decreasing, or steady temperatures, and no changes were observed on the samples.

In this connection it must be pointed out that both the loss-factor and the dielectric constant depend on the frequency; therefore it is incorrect to draw conclusions with regard to the behaviour of the material at a high frequency from its behaviour at say 50 cycles, and particularly in the case of special high-frequency material with a high content of titanium compounds.

Measurements show that within a certain temperature range a large number of ceramics follow the equation developed by Rasch and Hinrichsen, giving the specific resistance as a function of the temperature, namely:

$$\log \rho = \frac{\nu}{T} + C \quad .. \quad .. \quad .. \quad (2)$$

where ρ is the specific resistance, T the absolute temperature, and ν and C are constants. It is therefore expedient to plot the logarithm of the specific resistance against the reciprocal of the temperature T, which gives a clear picture of the process as well as allowing the validity of the above formula to be checked. Figs. 2 to 4 show the results of measurements on various kinds of ceramics. The characteristic curve of material "Tempa S" shows a peculiar shape which was confirmed by measurements on samples produced by different manufacturers. Also "Tempa T" seems to have a maximum peak which, however, occurs at a lower temperature.

Measurements carried out on samples of small capacity, as described above and with the described arrangement, were not successful at lower temperatures down to room temperature. Sufficiently accurate results in this range could, however, be obtained with the sample pieces described, if higher frequencies were used, although difficulties may be expected in the application of equation (1).

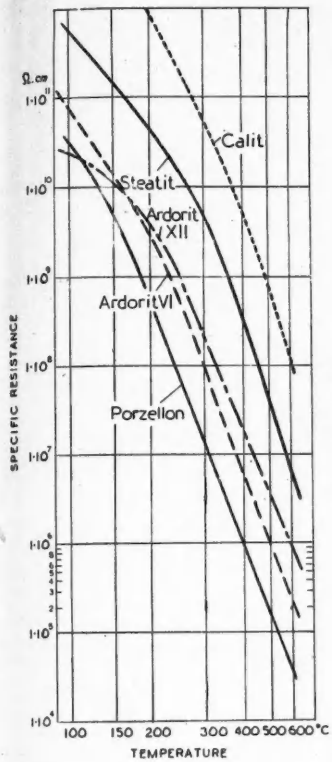


Fig. 2

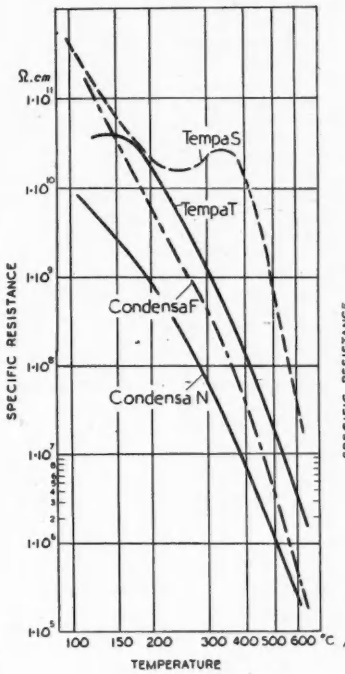


Fig. 3

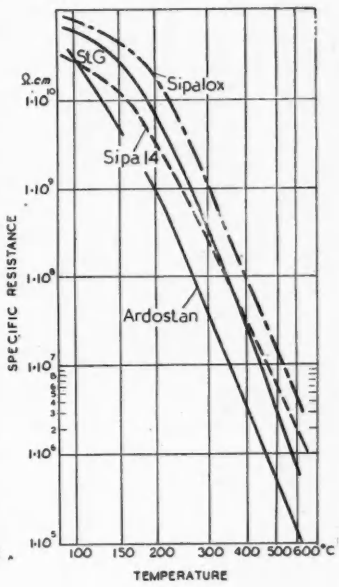


Fig. 4

The specific resistance of ceramics as a function of the temperature.

HARDENING OF PLASTICS BY HIGH-FREQUENCY POWER.

By H. STÄGER and F. HELD. (From *The Brown Boveri Review*, September, 1944, pp. 298-305).

GENERAL.

HITHERTO, plastic mouldings and laminated sheets have generally been hardened in presses with heated platens, i.e., the heat was applied to the exterior of the material. The heat conduction of the mixture to be moulded, however, is generally so poor, that the applied heat can penetrate only slowly into the interior. In order, therefore, to cut down the moulding times, especially where thick, laminated sheets are concerned, the material must be subjected to a subsequent hardening process in a stove without the application of pressure. Quite definite temperature ranges are required and with increasing thickness of the material longer heating times have to be allowed to attain the mean temperature.

Since the hardening process is dependent on the temperature the outer layers will have reached the final hardened state long before the interior. This non-uniform hardening process gives rise to non-uniform properties within the moulding. Intermediate reaction products, water, formaldehyde, low molecular condensation products, formed during the hardening process can no longer escape from the interior because the outer, directly heated zones are the first to become completely hard. This may lead to the formation of internal fissures, either during the pressing process or in service. From these considerations it is obvious that the present conventional method of hardening synthetic resins has big technical shortcomings.

The chemical changes taking place during the hardening process can be traced by determination of the volatile intermediate condensation products. The losses in weight observed for a given hardening temperature with different hardening times enable a hardening curve to be plotted. The originally fusible and soluble resole change to infusible, insoluble resites during the hardening process. The variation in the solubility of the material in alcohol or acetone, therefore, also enables the hardening process to be followed indirectly, as the percentage of soluble constituents diminishes as a function of the hardening time. The foregoing changes thus enable the hardening process to be followed, if not qualitatively, at least quantitatively.

HARDENING OF PLASTICS BY HIGH-FREQUENCY POWER.

The high frequency method has the advantage over the hardening in hot-plate presses that due to the dielectric loss phenomenon, the processing heat is developed in the interior of the material and has not to penetrate into it by conduction. When thermo-setting plastics are subject to a high frequency field the temperature is highest and, in consequence, the hardening process is most advanced in the very interior, so that the reaction products can be freely expelled from the beginning to the end of the hardening process. Further merits are shorter hardening times, lower power consumption,

and more uniformly hardened finished products than with any other process.

In their original condition the more common plastics have quite high power factors and corresponding dielectric constants, which are chiefly caused by the mobility of the polar groups in the high frequency field to which, however, must be added the mobility of the chain units. The power factor governs, inter alia, the power input and the heat produced in the electrical alternating field. During the hardening process the macromolecules of plastics become three dimensionally linked, especially in the resite formation stage, which considerably diminishes the mobility of the chain, and, due to intermediate reactions or steric hindrance, the mobility of the polar groups is more and more impaired. In consequence, the power factor becomes lower and lower in the course of the hardening process, with a corresponding variation in the dielectric constants. The reaction characteristic for the formation of phenol plastics leads one to assume that this class of plastics is particularly suitable for hardening by high frequency power, due to the large number of highly mobile polar (*OH*) groups occuring in the macromolecule.

With the high frequency method of heating the heat is uniformly distributed, especially in the interior of the moulding. Due to the radiation of heat from the outer zones a temperature gradient from the centre to the exterior occurs, as shown in Fig. 1. It will also be seen that the heating time is substantially shorter than when heat is applied externally. As a result it is also to be assumed that high frequency heating will allow of larger cross sections being heated up to the requisite hardening temperature in a shorter time than external heating.

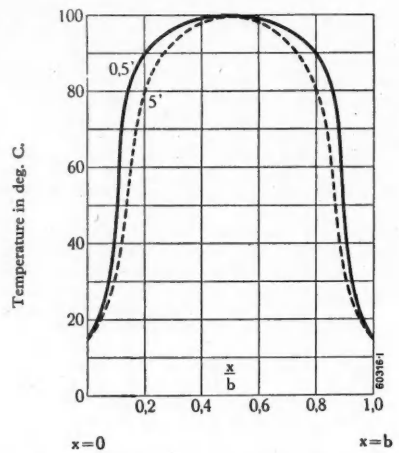


Fig. 1. Temperature distribution through a laminated sheet heated with high-frequency power, after 0.5 and 5 minutes, respectively.

TESTS UNDERTAKEN.

Tests were carried out with a view to ascertain the fundamental processes taking place in connection with the hardening of synthetic resins. The investigations were confined to the phenol class of thermo-setting plastics which is the most frequently employed in the manufacture of modern organic materials and which incidentally is particularly suitable for such tests. The investigations were carried out on pure resins whose power factor was made particularly high by the addition of salt in the proportions shown in Table I., and also on laminated material, i.e., plywood of beech and oak veneers 0.6 and 0.8 mm. thick, respectively. The behaviour of the latter varies during the heating process as the dielectric properties of the wood depend on the moisture content. Moreover, the interaction between the bonding agent and basic material may be different according to the previous treatment, type of bonding agent, and degree of compression.

TABLE I.—DIELECTRIC CONSTANT ϵ AND POWER FACTOR tan δ OF PURE RESIN WITH SALT ADDITIONS.

Pure resin with salt additions	Frequency in cycles									
	5×10^4		2×10^5		1×10^6		4×10^6		1.3×10^7	
	tan δ	ϵ	tan δ	ϵ	tan δ	ϵ	tan δ	ϵ	tan δ	ϵ
2% *NaOH*	0.167	12.0	0.118	11.3	0.098	10.2	0.094	9.2	0.089	
1% *NaCl*	0.057	9.2	0.059	8.8	0.060	8.2	0.065	7.7	0.069	
0.1% $AlCl_3$	0.074	9.9	0.066	9.2	0.064	8.6	0.069	8.2	0.069	

A self-excited 1.5 kW. high frequency electronic generator giving a frequency of about 23 megacycles was employed for the tests. The specimens of the pure resins tested were cylindrical, their diameter being 26 mm. and their height 28 mm., while the test-pieces of compressed laminated wood were cubes of 80 × 80 × 80 mm. Since the escaping intermediate reaction products are liable to cause the wood to split, a corresponding counter-pressure must be applied. As is shown in Fig. 2, the tests were carried out in a 20-ton press.

In order to enable the variation in temperature in the interior of the pure resin specimens to be followed during the hardening process, a fine hole was bored in the centre and a thermo-couple introduced, while a further temperature measuring point was arranged 5 mm. below the surface. If a symmetrical field is employed a thermo-couple can be used without risking any additional heating effect. The relation between the applied voltage and the temperature in a pure resin specimen with the addition of sodium lye as conducting medium is shown in Fig. 3. At a given voltage the temperature rises to a definite value and then drops off slowly again. This fact signifies that after the maximum temperature has been reached the corresponding hardening state is attained in a very short time and the temperature must then drop due to the condensation of the intermediate reaction products and the consequent reduction in the power factor. This observation is of significance for the fundamental elucidation of the mechanism of hardening of phenol resins.

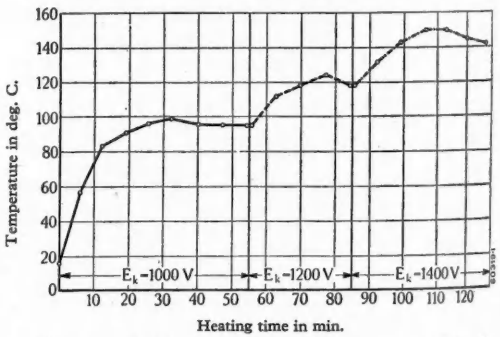


Fig. 3. Relation between hardening temperature in laminated materials and voltage of high-frequency field. For a given voltage the temperature rises to a maximum, then drops slightly, and does not attain another maximum value unless the voltage is increased.

Similar specimens were hardened in a high frequency field and in a conventional electrically heated stove. The *heating times* required to reach the desired hardening temperatures differ very widely for the two cases (Fig. 4).

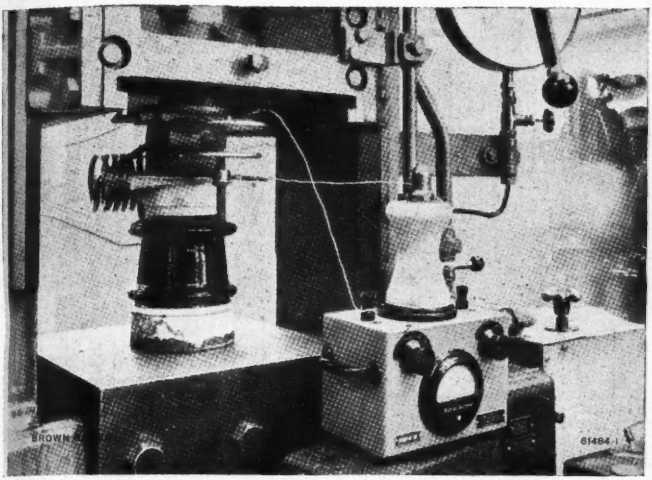


Fig. 2. **Test set-up for hardening laminated materials (compressed laminated wood) in a 20 t press.**

The high frequency power was supplied by an electronic generator.

The *hardening process* itself was followed by determining the losses in weight and the reduction in solubility in acetone. In order to obtain comparable hardening conditions the same heating conditions, as shown in Fig. 5, were selected for both the high frequency and stove methods of hardening.

When analysing the tests made on samples of pure resin with the addition of sodium lye as conducting medium it will be seen that the hardening losses are greater with the high-frequency method than with the conventional stoves (Fig. 6). As already inferred, this is due to the outer zones hardening in a conventional stove before the inner zones, thus preventing the intermediate condensation products escaping. The hardening effect is the most complete in the hardening stage II. due to the short heating period. If the resin is heated up slowly the hardening losses are about the same for both the high-frequency and the stove methods. It may therefore be concluded that the more rapid the temperature rise the better is the hardening effect.

The solubility of the samples in acetone was tested in a Soxhlet apparatus, and Fig. 7 gives the test results for the three hardening stages shown in Fig. 5. The

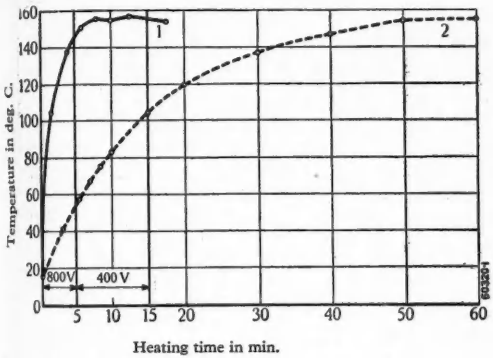


Fig. 4. **Comparison between temperature rise in pure phenolic resins in high-frequency field and in electrically-heated stove.**

The heating process takes place far more quickly in the high-frequency field (curve 1) than in the stove (curve 2).

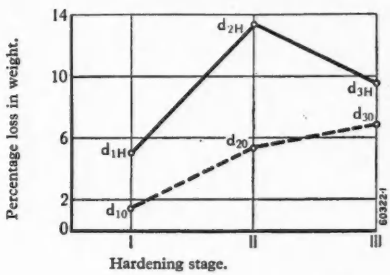


Fig. 6. **Relation between hardening losses of pure phenolic resins and hardening conditions shown in Fig. 8. Test series d.**

Dash line : Stove hardening.

Full line : Hardening by high-frequency power.

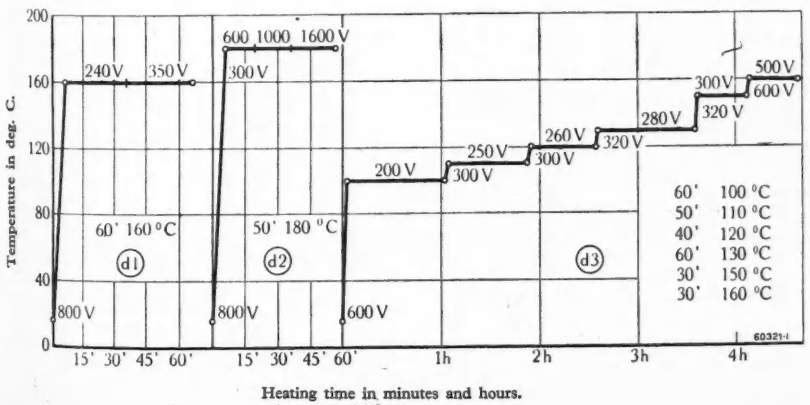


Fig. 5. **Characteristics of three different hardening conditions employed during tests, in relation to time, temperature, and voltage.**

In order to obtain comparable results these hardening conditions were employed both for stove and high-frequency heating.

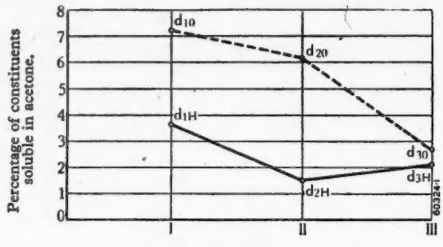


Fig. 7. Percentage of pure phenolic resins soluble in acetone in various hardening stages.
The stove-hardened resins contain a greater percentage of constituents soluble in acetone and are thus less uniformly hardened. Dash line: Stove hardening. Full line: High-frequency hardening.

solubility is at a minimum in stage II., and attains a value practically corresponding to the completely hardened condition. In stage III. the difference between the solubility of the high-frequency hardened and of the stove hardened samples is again smallest.

In laminated materials the dielectric properties of the resin vary in the course of the hardening process due to the associated chemical changes, while those of the basic material (in the present case wood veneer) can vary with changing moisture content. Since samples of the size used (80 × 80 × 80 mm.) involve long hardening times with external heating, the tests were confined to high frequency heating. Tests on smaller samples were unsuccessful due to the comparatively low resin content. The hardening stages employed for the tests are shown in Fig. 8. For the actual measurements of solubility test pieces were cut from the outside and inside zones as well as from the centre (Fig. 9). The results of these measurements are shown in Fig. 10.

In the case of laminated wood the acetone extracts contain, apart from the soluble elements of the thermosetting bonding agent, the soluble elements of the basic material, in the present case the wood veneers. In the case of specimen E (Fig. 10) an increase in the constituents soluble in acetone was observed. This was due to the fact that because of a too rapid voltage rise the wood veneer in the centre was already slightly damaged and even to some extent carbonised. This shows the necessity to choose the voltage carefully, since the power factor is highly dependent on the temperature which in turn is a function of the power factor.

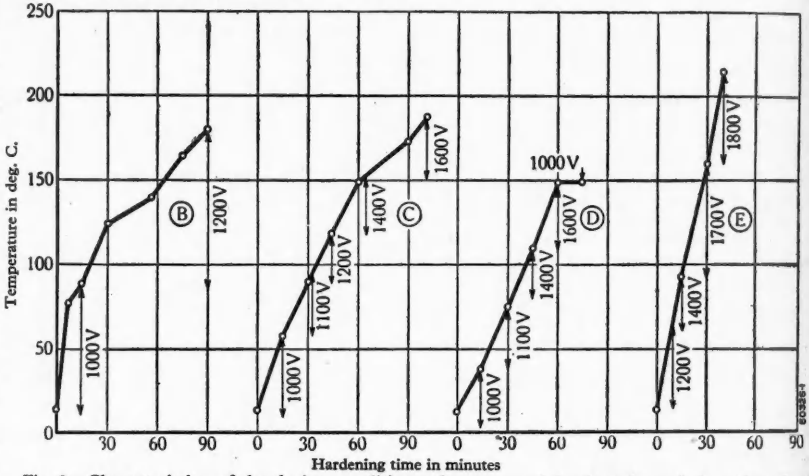


Fig. 8. Characteristics of hardening conditions of compressed laminated wood, investigated in relation to temperature, time, and voltage.

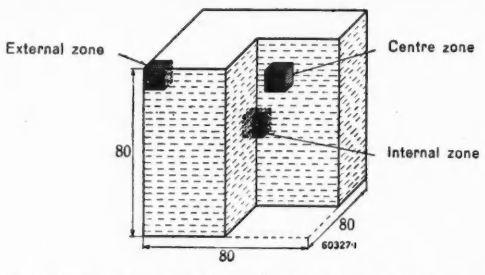


Fig. 9. Points from which specimens of compressed laminated wood were taken for tests.

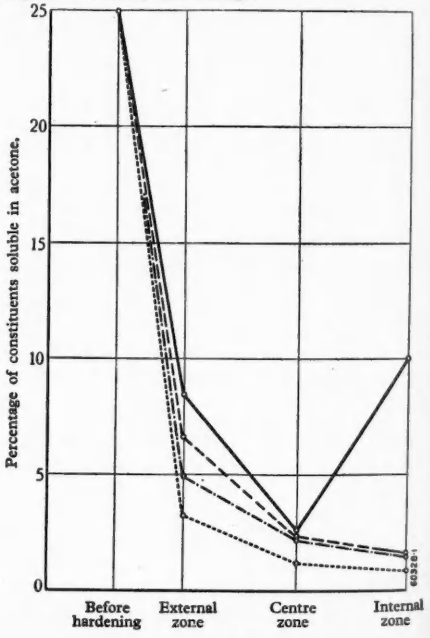


Fig. 10. Percentage of constituents of various specimens soluble in acetone (internal, centre, and external zones).
——— Specimen E - - - - Specimen C
—.—.— Specimen B ---------- Specimen D

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